SUSQUEHANNA RIVER BASIN COMMISSION

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COAL MINE DRAINAGE
IN THE
SUSQUEHANNA RIVER BASIN

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This study and enclosed color map were prepared under Contracts 61 and 89 respectively for the Susquehanna River Basin Commission by Skelly and Loy of Harrisburg, Pennsylvania.

Essentially this report updates and expands upon a report titled "Mine Drainage in the Susquehanna River Basin", prepared in 1968 by the Federal Water Pollution Control Administration.

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FOREWARD

This coal mine drainage (CMD) study, initiated under the Susquehanna River Basin Commission's Project Number 61 in April 1973 and completed by Skelly and Loy in September 1973, updates previous investigations undertaken by the Federal Water Pollution Control Administration (FWPCA) from 1962 to 1968. The original study (27) was done by the staff of the Susquehanna Field Station, a branch of the comprehensive program of the Middle Atlantic Region which was assisted by State and other Federal agencies. The first study was part of a comprehensive survey of water quality and pollution problems affecting the Susquehanna River Basin which was initiated by the Federal Water Pollution Control Act (33 U.S.C. 466 et. seq.).

This update, as did the original report, treats coal mine drainage separately as a major form of pollution in terms of water quality degradation and total abatement costs. Coal mine drainage is the only form of water quality degradation in many otherwise unpolluted tributary streams. Other tributary streams, in addition to being polluted by coal mine drainage (CMD), are also degraded by other forms of pollutants. The bulk of CMD is from the many abandoned mines versus active mines.

During this current study numerous reports of localized area studies of mine drainage (MD) problems were consulted. All recent and available CMD water quality data was obtained for all mine drainage affected streams

and major CMD discharges within the basin. Evaluations of abatement methods, their costs, and effectiveness were analyzed for application to specific watershed CMD problems. Benefits derived directly from water quality improvement in restoration of surface lands were computed. Benefits in terms of dollars were weighed against abatement cost to establish priorities for future mine drainage abatement projects on a local and comprehensive basis.

This report utilizes several abbreviations extensively to eliminate constant repetition of commonly used phrases to increase reading ease.

AMD - acid mine drainage

Basin - Susquehanna River Basin

cfs - cubic feet per second (flow)

CMD - coal mine drainage (not necessarily acid)

"deep" mine - subsurface (underground) extraction of coal

DER - Pennsylvania Department of Environmental Resources

drift - underground mine entryway

EPA - Environmental Protection Agency, Region III

ENR - Engineering News - Record

FWPCA - Federal Water Pollution Control Administration

MD - mine drainage (which may be alkaline or acid)

mg/d - million gallons per day (flow)

mm - millimeter (of mercury)

pH - the common logarithm of the reciprocal of the hydrogen--ion concentration

ppd - pounds per day (loading)

ppm - parts per million (concentration)

slug - periodic high concentration of AMD in a stream

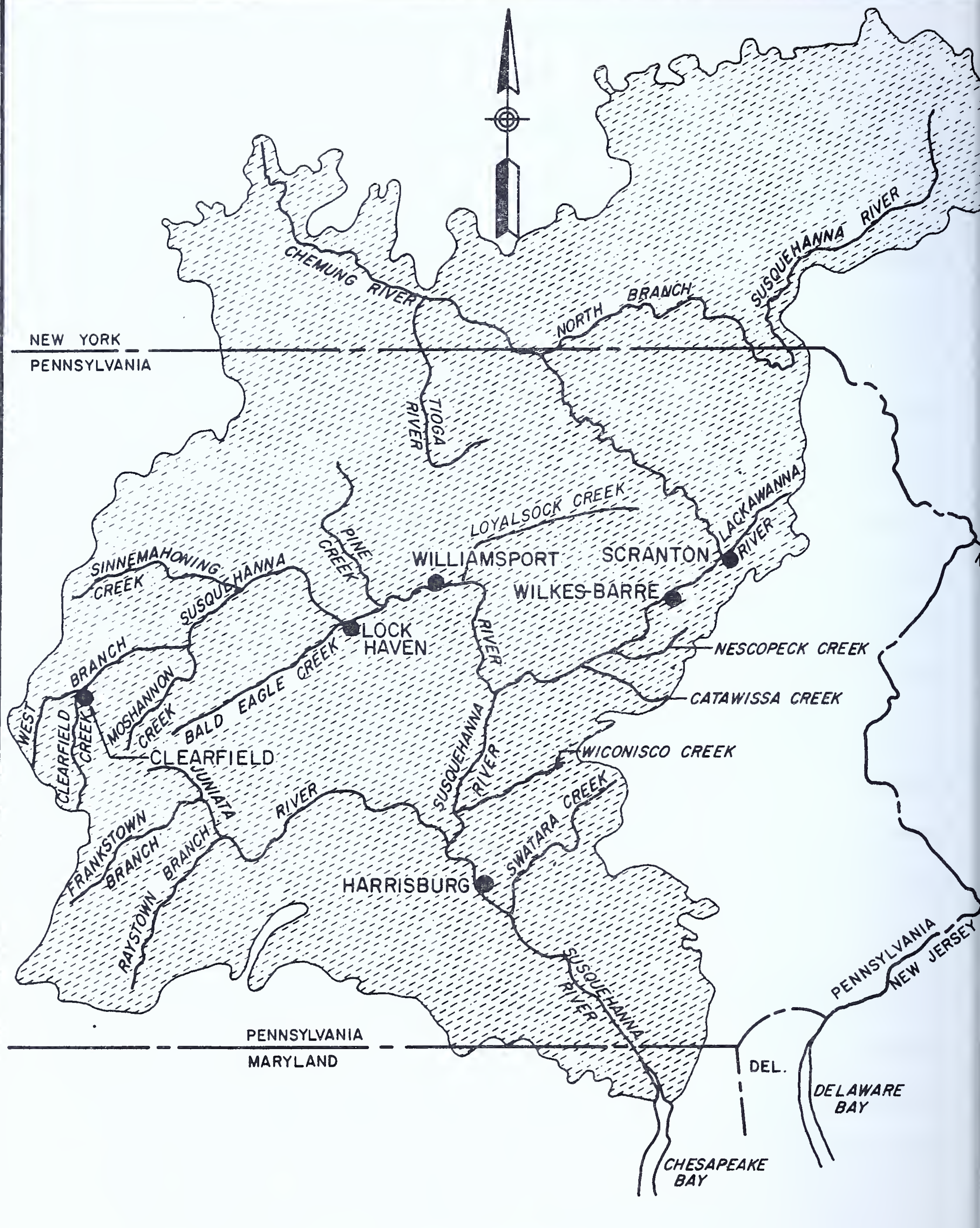
U.S.G.S. - United States Geological Survey

INTRODUCTION

Coal mine drainage has degraded many streams in the Susquehanna River Basin (see location map - figure 1) since the middle 1800's. Most of this drainage has and continues to emanate from numerous deep mines, a few of which were abandoned over 100 years ago. A significant amount of drainage from coal mines is acid and contains high concentrations of dissolved solids. These are often incompatible with life immediately within the stream's influence and with many of man's domestic and industrial needs. Mine drainage involves the interplay of natural phenomena and man's activities increasing the production of pollution, some of which will continue almost indefinitely until corrective action is taken.

In the past, many areas were dominated by mining activities which were the backbone of local economies. In the Hazleton area (Eastern-Middle Anthracite Field), the coal mining industry in the early 1900's supported 85 percent of the economy. Today this dependency has been reduced to 15 percent (61). This is also reflected by current anthracite production trends (12). In some bituminous mining areas within the Basin coal still plays a significant role in the economy (13). In many other areas, especially the Anthracite Region, many forms of diversified industry have created a new but moderate economic boom that partially offsets the decline of the coal industry.

Population increases have created a need for more clean water and



LOCATION MAP
SUSQUEHANNA RIVER BASIN
Scale : 1" = 30 Miles

Figure 1

restored mined lands which can provide the people with their basic and recreational needs. Many local and state leaders have realized for sometime that our land and water resources must be conserved and improved. The accumulating land and water resource loss can no longer be traded off for the value of coal that is mined.

During World War II, strip mine production peaked at nearly 39 million tons in Pennsylvania (12,13). Since then the yearly production has decreased. Previous to 1945, Pennsylvania had no strip mine regulatory laws governing either mining methods or the discharge of mine drainage. In May of 1945 an amendment to the Clean Streams Law included acid mine drainage in its jurisdiction. In 1963 the Bureau of Conservation and Reclamation was established in the Department of Mines and Mineral Industries under an amendment to the Bituminous Coal Open Pit Mining Conservation Act. This amendment provided for a minimum performance bond of $500 per acre, and required that restoration work be done in accordance with the terrain. In 1964 the coal industry was required to bring their operations into compliance with this law. Present reclamation work under current law appears to have practically eliminated future production of pollution from strip mines. Many acres of old abandoned strip mine lands are being reclaimed by strip mine operators as they

remine previously mined areas. This restoration work is affecting about 15.6 square miles of land annually. Additional strip mining in Pennsylvania will reclaim a small portion of the many acres of denuded lands. This will relieve some of the burden on the taxpayer. However, much more research, reclamation work, and money will be required to complete the reclamation of abandoned mine lands.

DER is currently directing the expenditure of 150 million dollars, a portion of a 500 million dollar bond issue, to study and abate acid mine drainage under a program termed "Operation Scarlift." Other programs have been directed toward the abatement of acid mine drainage. Pennsylvania's former Coal Research Board sponsored "Operation Yellowboy," a pilot treatment plant, and an experimental Mine Drainage Treatment Plant at Hollywood, Pennsylvania. Pennsylvania State University's Mine Drainage Research Section is actively researching and providing educational services related to the abatement of mine drainage. Several federal agencies are conducting research, study and demonstration projects on the abatement of acid mine drainage.

Much has been learned about the formation of acid mine drainage within the Susquehanna River Basin within the last ten years. Numerous studies have been conducted to determine the severity of AMD pollution and recommend remedial measures for nearly all the polluted watersheds

in the Basin. In addition to this work, abatement techniques, both preventive and treatment, are being tested for their effectiveness or applicability to specific acid mine drainage problems. The advancement of technology for the abatement of mine drainage pollution is a continuing effort and a great future challenge. Many watersheds in the Main Bituminous Field are affected by acid mine drainage discharges from deep mines for which technologically or economically feasible abatement methods are not available. Since the majority of AMD is from abandoned mines, the assignment of responsibility for abatement is difficult. Consequently, the responsibility for abatement will have to be assumed by governmental agencies.

This report defines acid mine drainage problems within the Basin, suggests abatement solutions of known effectiveness, and estimates their initial and annual cost. This study also deals with the justification of these expenditures in terms of yearly accumulative benefits realized from the utilization of many miles of improved streams and thousands of acres of restored lands. Further, this report also suggests that certain areas receive higher priority for abatement work than others in accordance with dollar benefits realized. This report is a step toward the development of a basin-wide comprehensive acid mine drainage abatement plan.

Only a small part of the Susquehanna Basin is underlain by coal

deposits. These coal deposits are grouped into the following coal fields and shown on plate 1.

Anthracite	Northern, Western-Middle, Eastern-Middle, and Southern Fields	529 sq.mi.
North Central	Mehoopany, Towanda, Pine, Loyal-sock Creek Basins, Tioga River Basin	114 sq.mi.
Broad Top	Juniata River Basin (Raystown Branch and Augwick Creek)	81 sq.mi.
Main Bituminous	West Branch Susquehanna River West of Lock Haven and Northwest Juniata River	3,606 sq.mi.

PURPOSE AND SCOPE

This report provides a current record of the severity and causes of coal mine drainage in the Susquehanna River Basin based upon a background of the most recent data available. The three principal objectives of this report are to: (1) describe geographically, qualitatively, and quantitatively all significant amounts of coal mine drainage and affected streams, (2) present feasible and applicable abatement measures which would eliminate or reduce this pollution to tolerable levels and an estimate of abatement costs, and (3) determine if these expenditures are justified in the form of benefits (substantiated dollar values) accrued as a result of this abatement. All forms of benefits were analyzed both locally and as far downstream as the effects of mine drainage were noticed.

The amount of coal fines and sand, silt, and clay sediments carried by the Susquehanna River from areas affected by coal mining and processing operations were also derived. Estimates of average annual sediment yields are based on recent coal dredging activities and hydrologic studies of sub-basins affected by mining activities in the Susquehanna River Basin. For comparison purposes, sediment yields from non-coal oriented activities were also calculated.

It must be kept in mind that stream water quality is very dynamic and variable. Any flow measurements or water quality data of mine drain-

age waters recorded for a given moment are not usually representative of either normal or average conditions. Presently prevailing conditions of precipitation, temperature, season of the year, vegetative cover, sampling method, and many other factors heavily influence sampling results. In most cases, when an extensive sampling program was not conducted, more than one source of data was consulted to provide the best characterization of mine drainage effects in an area. Information contained in this report should provide state and federal agencies with some of the data needed to formulate a comprehensive and effective program to enhance the environmental quality of the Basin at minimum cost and maximum benefit.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the aid and guidance of Jerrald R. Hollowell, Project Manager for the Susquehanna River Basin Commission. Many hydrogeologic aspects of the Basin's coal measures, in particular the Anthracite Region, are well known by Mr. Hollowell, who contributed much of this information and was responsible for the spirit of cooperation enjoyed by the authors while working with various state and federal agencies throughout this project.

The authors further wish to acknowledge persons who were frequently contacted and gave willingly of their time to supply information required for this project. These persons and their area of expertise are listed in the bibliography.

SUMMARY AND CONCLUSIONS

This report culminates a six-month study updating previous coal mine drainage investigations in the Susquehanna River Basin. This report was concerned with the following four appraisals: (1) quantifying the severity of CMD currently polluting the Basin's tributaries and main streams; (2) ascertaining the sources of major CMD discharges causing this stream pollution; (3) determining the cost and applicability of various abatement measures and recommending a feasible combination of abatement methods which would reduce stream pollution and restore utility to stripped land; and (4) establishing a full range of benefits, derived from cleaned streams and restored lands, in order to justify abatement expenditures and determine priorities or the relative desirability of abating CMD within the Basin's polluted watersheds.

For the purposes of this report the Basin is divided into four distinct sub-basins: the West Branch of the Susquehanna River; the Juniata River; the Tioga River; and that portion of the Basin draining the Anthracite Region tributary to the Susquehanna River. Each affected watershed within the four major sub-basins is geographically described and shown on a location map.

Information on the geology, coal mining history and coal reserves, is given for each of the four sub-basins. Mine drainage sections describe the causes and magnitude of stream pollution, give applicable abatement recommendations, and estimates of costs. Estimates of the number of miles of main streams and tributary streams which are degraded by CMD are given. A total of 712 miles of main stream and 592 miles of tributary streams are polluted within the Basin. Abandoned deep mine discharges contribute more than 75 percent of all the Basin's AMD. The greatest single discharges of AMD emanate from mine pool overflows in the Northern Anthracite Field. Numerous smaller discharges emanate from deep mines in the soft coal fields which cause wide spread degradation of the area's streams. Within the Anthracite Field major discharges of AMD contribute 982,600 pounds per day acid. Major discharges within the Bituminous Fields contribute 800,000 ppd acid.

Current preventive abatement costs indicate that complete surface restoration in the Bituminous Fields costs about $2,000 per acre. Costs in the Anthracite Region are at least twice as great, about $4,400 to $5,000 per acre. Stream and land oriented benefits accumulated for the first 30 years return $1.27 for every dollar spent for reclamation work in the entire Basin. Most benefits will exceed the cost of all recommended reclamation work in less than 30 years.

Of course, many of the benefits will accrue for a longer period than 30 years. Many of the preventive measures provide permanent solutions and would justify accumulating benefits over a much greater period than 30 years. This would significantly raise benefit cost ratios.

Coal mine drainage is a major source of pollution in the Susquehanna River Basin. The Commonwealth of Pennsylvania has applied stringent controls on the active mining industry in the last ten years. Presently active and future mines are not expected to increase the amount of coal mine drainage pollution in the Basin. The present conditions of the Basin's waterways are expected to remain relatively stable unless specific remedial action is taken. The present levels of acid mine drainage are primarily from abandoned mines. Some of these discharges will continue to be pollution sources unless new technology is forthcoming. The coal mining industry does remine some abandoned mine areas that will provide some water quality improvement. The Pennsylvania Department of Environmental Resources is performing abatement work under "Operation Scarlift." Some water quality improvement will result from this program.

Massive funding will be required to complete the abatement recommended in this report. Initial costs of abatement work totals $216 million with on-going costs of $6.6 million. The magnitude of this expen-

diture is far beyond the scope of present Pennsylvania and Federal funding sources. A massive infusion of funds is required to eliminate the effects of mine originated water pollution and land ravages.

The expenditure of the funds recommended in this report is justified from the analysis of a full range of benefits that will accrue from restoring utility to the land and streams degraded by mining practices. The total expenditure over a thirty-year period is estimated to be $407.7 million. The benefits to accrue over this same thirty-year period are estimated at $520.0 million for a benefit cost ratio of 1.27 for the entire Basin. Many watersheds exhibit significantly higher benefit cost ratios and should receive higher priority. Basin-wide priorities were established on the basis of benefit cost ratios. It is recommended that efforts be concentrated in the high priority areas first. It is not recommended that complete abatement be performed in the higher priority areas before the initiation or work in lower priority areas. Benefits can be further maximized by doing selected projects in many of the watersheds simultaneously. It must be stressed that all benefits do not accrue in proportion to funds expended. Water quality improvement benefits do not accrue until a stream is returned to utility. A large expenditure is required to elevate stream water quality to just below the point where utility is returned. However, water quality improvement benefits are minimal at this point. The next expenditure that causes the water quality to surpass this utility threshold will then allow most of the

benefits to accrue. Wise expenditure of limited funds is therefore required to insure that projected benefits will accrue. Watershed ranking of priorities for pollution abatement on a local and comprehensive basis are shown on Table 1.

TABLE 1 - Pollution Abatement Priority Ranking

Watersheds	Local	Comprehensi
Bituminous Region		
West Branch (Upstream from Chest Creek)	5	8
Chest Creek	2	4
West Branch (Chest Creek to Clearfield Creek)	1	1
Anderson Creek	10	13
Clearfield Creek	7	10
West Branch (Clearfield Creek to Moshannon Creek)	9	12
Moshannon Creek	6	9
West Branch (Moshannon Creek to Sinnemahoning Creek)	4	7
Sinnemahoning Creek	8	11
West Branch (Sinnemahoning Creek to Bald Eagle Creek)	11	14
Bald Eagle Creek	12	20
West Branch (Bald Eagle to Mouth of West Branch)	3	5
Juniata River Basin		15
Tioga River Basin		2
Anthracite Region		
Lackawanna Valley	8	22
Lackawanna River to Nescopeck Creek	9	23
Nescopeck Creek	7	21
Catawissa Creek	2	6
Shamokin Creek	5	18
Mahonoy Creek	4	17
Rausch Creek	6	19
Wiconisco Creek	3	16
Swatara Creek	1	3

STUDY PROCEDURE

Since the latter part of 1967, a vast amount of information regarding the occurrence and abatement of coal mine drainage has been reported. Numerous AMD studies have been conducted and many more are in progress. Recent studies have gathered water quality data for many large AMD discharges and mainstreams. This information has made possible a thorough update of previous studies of AMD in the Basin (27).

Numerous state and federal agencies were contacted for information needed to define current AMD problems in each watershed of the Susquehanna River Basin significantly degraded by AMD. Where published information on a watershed was lacking, individuals known to possess such information were contacted personally. Old information was evaluated with respect to the most recent data available to determine possible trends in water quality changes. When very little information was available for a particular watershed, data for similar or adjacent watersheds was utilized to represent AMD conditions for watersheds lacking suitable data. Surface water discharge conditions were estimated for each watershed to determine if listed flow values would cause poor estimation of AMD loadings. An estimated yearly average flow can be computed for any watershed area. A comparison of this estimation with

the measured flow values indicates whether the measured flows closely approximate average conditions. Flows were often measured during the dry low flow periods of the summer and early fall. Acid loading values computed from low flows will be less than what would be expected under yearly average conditions. All watersheds were examined to determine the primary causes of AMD formation. The most applicable combination of abatement methods which would eliminate or decrease the production of AMD to tolerable levels were recommended.

Different preventive abatement cost estimates were used for the Main Bituminous Field and the Anthracite Fields. Cost estimates for abatement in the soft coal fields (bituminous) were based on recent pollution control costs developed for the Appalachian Regional Commission (3). Cost estimates for the hard coal region (anthracite) were based on recent bids accepted by the Pennsylvania Department of Environmental Resources (DER) for AMD reclamation work in the Anthracite Fields (45). AMD abatement costs were adjusted, if required, using a December 1972 construction cost index value.

Preventive abatement measures were recommended wherever possible to facilitate funding and maintenance. Use of preventative measures results in a large initial capital investment but minor or zero yearly maintenance costs. Preventive measures are generally the most acceptable form of AMD control and they usually result in significant land improvements.

Treatment, on the other hand, is a continual expense that results in water quality improvement benefits that only apply as long as treatment continues. Treatment incurs the commitment of yearly operating costs for an indefinite period. If, for any reason, funds become unavailable, treatment is discontinued and the stream will return to its pre-treatment condition and benefits would be limited to the period of plant operation. Preventative measures are often inadequate in reducing AMD effects to tolerable levels in many watersheds. In such cases treatment is recommended. Total abatement costs are prohibitively expensive in some areas of the West Branch and total abatement is not always recommended. For this reason, abatement costs for some areas in the West Branch are less than reported by the FWPCA.

Thorough investigations of AMD production in several watersheds in the Basin are still in progress and (50), when completed, these should provide a more accurate and complete account of AMD problems along with abatement recommendations and estimated costs.

Estimates of sediment discharged from coal mining operations were made by comparing average annual sediment yields for similar areas with and without coal mining activities. Data on organic sediments were obtained from coal dredging operations (76) near the mouth of the Susquehanna River and studies of organic sediment in the northern Chesapeake Bay (8).

Dollar values were derived for all benefits related to the restoration

of utility to streams and stripped lands. Information was obtained from recent reports which contained realistic dollar estimates of values of timber, farm produce, land values, recreational activities, and other benefits. Where dollar values were not available, sufficient information was obtained to allow an estimation of these values to minimize assumptions and maximize reliability.

Priorities were established on a local and comprehensive basis from estimates of pollution which can most realistically be abated using current methods and cost. Unrealistic and excessively high cost, primarily due to treatment of AMD, were avoided in the establishment of priorities. Unlike the FWPCA report, estimates of yearly accumulating (not a single year's) benefits were matched against abatement costs to provide a more realistic benefit/cost ratio. In this way priorities and possible alternatives, justified by long-term benefits cost, could be selected in accordance with funding availability of various local, state, and federal environmental programs.

Priorities should be established by including considerations of other types of pollution in the Basin along with socio-economic parameters, needs for recreational facilities, optimization of land use, demands for energy, and other natural resources. These factors should be correlated in a total environmental program with realistic long-range objectives.

TOPOGRAPHY AND CLIMATE

TOPOGRAPHIC FEATURES

The part of the Basin affected by CMD can be discussed more readily when it is divided into three individual areas. The northern area is high, rolling ground with elevations mostly between 1,200 and 1,600 feet above sea level, however, in some places mountain peaks reach as high as 2,500 feet. This area is classified as a poor agricultural location because the growing season is occasionally too short and the average annual rainfall is 36 inches. There is some dairying done in the area, and its major crop is buckwheat. Bradford County is the largest producer of buckwheat in the state.

The central part of this area is traversed from northeast to southwest by several parallel mountain ridges with elevations ranging from 1,500 to 2,500 feet above sea level, with deep and picturesque valleys. The valley lands in this part of the area lie between elevations 400 and 800 feet and are generally fertile and highly cultivated. The Susquehanna River has a moderate fall through this region, averaging about 2 feet per mile, whereas the headwaters of the West Branch, the Juniata, and most of the smaller tributaries to the Susquehanna have a fairly rapid flow. These streams are subject to sudden rises that sometimes do considerable damage. The average precipitation in this region is about 42 inches per annum (37). Damaging frosts seldom affect the valley lands, and the valley of the West Branch of the

Susquehanna, up as far as Lock Haven, has an average growing season nearly as long as that of the southern counties. Many acres of land in this area are suitable for corn, grain, vegetables, and pasture.

The southeastern part of the section is mostly rolling and undulated agricultural lands with average elevations between 400 and 500 feet. These lands are mostly in a high state of cultivation, and may be classed among the finest agricultural lands to be found in Pennsylvania. The growing season is ample for all crops that are native to the latitude, and for some kinds of vegetables that are ordinarily grown in more southerly states. Tobacco is extensively grown in this area. The precipitation in this area is dependable, and it averages about 42 inches yearly. The Lower Susquehanna River, for a distance of about 20 miles above the Maryland state line, flows through a type of gorge. Its fall is rapid, being a little more than 6 feet per mile, and is suited for power development on a large scale. A large power plant has been in operation at Holtwood for many years, and another is located at Safe Harbor about 8 or 9 miles farther upstream, while one of the larger plants in the country is at Conowingo, Maryland, about 4 miles below the Pennsylvania state line.

PRECIPITATION

The average rainfall for the central part of the basin is 39.75 inches (36,37). The snowfall is moderately heavy in this area, averaging about

50 inches annually in the northern and from 35 to 40 inches in the southern part. There is a narrow belt along the western border of the section where the snowfall average is above 60 inches. Light snow usually occurs in November and April, which averages about 1 to 2 inches, and heavy snow occurs between the months of December and March. The southern part of the basin is subject to severe thunderstorms; heavy local rains amounting to 5 or 6 inches in 24 hours and to as much as 8 or 9 inches for a single storm have been recorded in many instances.

TEMPERATURE

The temperatures in the northern part of the basin are as much as 6 degrees cooler than those in the southern part. In the northern highlands the summer mean temperature is about 67 degrees, and the winter mean is about 24 degrees (36, 37). In the southern part the summer mean temperature is 72 degrees and the winter mean is 30 degrees. The southern lowlands experiences 100 degree days practically every summer season, while mid-winter temperatures of 20 to 25 degrees below zero are occasionally recorded in the northern highlands and in the south central mountains. Temperatures of 90 degrees and above are recorded an average of 10 days for each summer season, while the average number of days with temperatures below 32 degrees is a little more than 100 for each winter season (36, 37). The last killing frost in spring for the southern part of the basin usually occurs

about the middle of May, and the first in autumn occurs about the middle of October, which allows approximately 6 months or 180 days for a growing season.

The following charts provide the reader with a geographical representation of average annual precipitation and temperature within the Susquehanna River Basin. Climate in the West Branch sub-basin is typical of the northern-western, northern-middle, and central-middle areas; the Tioga sub-basin - the central-western and southern-western areas; and the anthracite region - by the eastern areas.

AVERAGE ANNUAL PRECIPITATION
1951 THROUGH 1960

	Western	Middle	Eastern
rthern	Austinburg 33.14" Renovo 37.70"	Lawrenceville 32.54" Williamsport 40.46"	Montrose 40.61" Scranton 38.77"
ntral	Clearfield 42.80" Altoona 44.42"	Lock Haven 40.43" Bellefonte 37.49"	Shamokin 42.71" Sunbury 38.32"
uthern	Everett 38.61" Huntingdon 39.32"	Bloserville 42.71" Carlisle 40.76"	Harrisburg 39.62" Lebanon 45.04"

SUSQUEHANNA RIVER BASIN
CLIMATOLOGY RECORDING STATIONS

AVERAGE NUMBER DAYS PER YEAR WITH PRECIPITATION
1951 THROUGH 1960

	Western	Middle	Eastern
Northern	Austinburg 103 Renovo 106	Lawrenceville 97 Williamsport 111	Montrose 115 Scranton 110
Central	Clearfield 122 Altoona 125	Lock Haven 111 Bellefonte 108	Shamokin 107 Sunbury 108
Southern	Everett 112 Huntingdon 107	Bloserville 103 Carlisle 106	Harrisburg 102 Lebanon 109

SUSQUEHANNA RIVER BASIN
CLIMATOLOGY RECORDING STATIONS

AVERAGE ANNUAL TEMPERATURE
1951 THROUGH 1960

	Western	Middle	Eastern
lorthern	Austinburg 43.4 Renovo 45.4	Lawrenceville 46.9 Williamsport 50.8	Montrose 45.1 Scranton 50.2
entral	Clearfield 49.4 Altoona 49.7	Lock Haven 51.0 Bellefonte 49.3	Shamokin 50.8 Sunbury 50.7
outhern	Everett 51.0 Huntingdon 50.6	Bloserville 53.3 Carlisle 54.0	Harrisburg 53.4 Lebanon 52.0

SUSQUEHANNA RIVER BASIN
CLIMATOLOGY RECORDING STATIONS

ORIGIN OF COAL MINE DRAINAGE

CHEMICAL AND HYDROGEOLOGICAL ASPECTS

The study of the origin and chemistry of acid coal mine drainage has engendered some disagreement and uncertainty among leading authorities. This report does not intend to establish definite criteria in this field, but rather present a general scope of what is known by either fact or theory.

Basically acid coal mine drainage develops through a series of complex chemical, biochemical, and physical steps in which disulfide minerals, usually pyrite, are converted into various unstable and soluble substances. These substances may either be dissolved in ground waters or remain partially crystallized on coal or associated shale surfaces.

Formation of acid coal mine drainage is for the most part dependent upon: the amount, spatial distribution, crystallinity, and size of pyrite particles; flow rates and water levels within a mine; availability of dissolved and undissolved oxygen; the presence of certain bacteria associated with mine waters; and the alkaline producing potential of neighboring rock units. Although the processes are not fully understood, acid mine drainage can result from the oxidation of pyrite (FeS_2) as shown in reaction 1.

(1) $2FeS_2 + 2H_2O + 7O_2 \rightarrow 2FeSO_4 + 2H_2SO_4$ + Heat (688 K cal.)
Pyrite + Water + Oxygen → Ferrous Sulfate + Sulfuric Acid

(2) $4FeSO_4 + 2H_2SO_4 + 2O_2 \rightarrow 2Fe_2(SO_4)_3 + 2H_2O$
Ferrous Sulfate + Sulfuric Acid + Oxygen → Ferric Sulfate + Water

Hydrolysis of ferric sulfate is shown in reactions 3 and 4.

(3) $Fe_2(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3 + 3H_2SO_4$
Ferric Sulfate + Water → Ferric Hydroxide + Sulfuric Acid

(4) $Fe_2(SO_4)_3 + 2H_2O \rightarrow 2Fe(OH)(SO_4) + H_2SO_4$
Ferric Sulfate + Water → Basic Ferric Sulfate + Sulfuric Acid

Pyrite oxidation also occurs due to presence of ferric iron as in reaction 5.

(5) $14Fe^{+++} + FeS_2 + 8H_2O \rightarrow 15Fe^{++} + 2SO_4^{=} + 16H^{+}$
Iron + Pyrite + Water → Iron + Sulfate + Hydrogen nuclei

There are three basic substances involved in the formation of acid mine drainage: (1) pyrite, (2) oxygen, and (3) water.

More comprehensive discussions of the formation and causes of CMD go beyond the scope of this report. Interested readers can refer to papers presented before the Symposia on Coal Mine Drainage Research or a paper presented at a Short Course on Controlling Water Pollution in Coal Mining by Dr. H. L. Lovell titled Chemistry of Mine Drainage Formation (25).

Water quality data were obtained from a number of different sources for the same watersheds in order to ascertain the most realistic or rep-

resentative stream loadings. Water quality data utilized during this study was taken over the past four to five years and reflects, in many cases, the most recent watershed AMD conditions known. This data was collected from Pennsylvania's Operation Scarlift studies and from other agencies which are monitoring known problem areas. Since tropical storm Agnes some discharges, especially in the Anthracite Region, have changed their flow behavior and water quality. These new conditions may alter previously established costs and priorities within the Anthracite Region.

THE SIGNIFICANCE OF MINE DRAINAGE PARAMETERS

pH is a measure of the range of hydrogen and hydroxyl ion concentrations which exist. It is the common logarithm of the reciprocal of the hydrogen-ion concentration. Solutions with a pH of 6.0 have ten times as many hydrogen ions as solutions with a pH of 7.0, a value which indicates equivalent concentrations of both hydrogen and hydroxyl ions. From an ecological standpoint pH relates very well to the biological activity or potential of a stream. Treatment plant control and government water quality standards also utilize pH as a measurement of water quality. Values of pH may commonly range from 1.9 to 6.5 with titratable acidity ranging from 1-15,000 ppm (25), and free acidity and alkalinity ranging from 0-500 PPM. Values of pH can only be considered as a semi-quantitative

measure and are not directly related to titratable acidity. Coal mine drainage is chemically quite complex and contains a number of ions and complexes which control the availability of free hydrogen ions. For example, the small ferric ion, stripped of its three electrons, has the remaining electrons held tight with its three excessive positive charges. Three adjacent water molecules with negative forces are attracted to and hydrate the ferric ion, and the resulting configuration frees hydrogen nuclei, yielding additional acidity.

Acidity is usually expressed in terms of the number of parts per million $CaCO_3$ required, regardless of the reactions which take place, to attain a stable pH value of 8.3. In this way it serves as a meaningful measure of water pollution potentials, and a basis for calculating the amount of treatment coal mine drainage requires. Acidity values obtained from laboratory water sample analysis are usually trustworthy with regard to any alteration between sampling and analysis since these conditions are taken into consideration during analysis. Mineral acidity is obtained without disrupting the carbonate-bicarbonate-carbon dioxide equilibrium and the presence of acid salts such as iron, mentioned above, which can contribute to mineral acidity. Acidity can be determined by titration to pH 8.3, which measures uncombined hydrogen ions immediately present and that available from all potential sources. However, in samples

containing high concentrations of acid precursors, the total potential acidity may not become available unless pre-oxidation by some substance or heating occurs. Hot acidity is determined by heating the sample to boiling with the addition of hydrogen peroxide. Both hot (if boiled) and cold acidity are expressed in ppm of $CaCO_3$.

Alkalinity is determined by titration of the sample to a pH of 4.5. Most titratable alkalinity encountered in the Basin is bicarbonate or carbonate in origin and the results are expressed in PPM of $CaCO_3$. If acidity is considered equivalent to negative alkalinity, the two determinations--alkalinity and acidity--are added together to yield net alkalinity.

Iron is usually analyzed for ferrous and total iron. Iron concentrations are likely to change between sampling and analysis if allowed to do so. This occurs through the oxidation of ferrous iron or the hydrolysis of ferric iron. Iron is not uncommon in concentrations as high as 500 ppm ferrous and 700 ppm total iron. Mine drainage usually contains both forms of iron, however, if ferrous iron is found in relatively high concentrations in a receiving stream it usually indicates a recent discharge.

Sulfate is a good indicator of the amount of pyrite oxidized because it is the more stable component of coal mine drainage. Coal mine drainage

emanating from high reactive sulfur seams can have 1,000 to 5,000 ppm sulfate. A discharge of one million gallons per day, having a sulfate concentration of 2,500 ppm, would have reacted with 8,000 pounds of pyrite. Sulfate ion concentrations also relate closely to the conductivity of mine drainage. Analysis of mine drainage from one treatment facility yielded sulfate ion ppm concentrations and corresponding conductivities in micromhos, which were curve fit with a fifth order polynomial with only a 6.5 percent average deviation (25).

Other elements of coal mine drainage that do not cause as great a problem are calcium, magnesium, manganese, and aluminum. Both calcium and magnesium are components of hardness. Concentrations in unpolluted waters range near 22 ppm calcium and 18 ppm magnesium. Manganese is usually an acidic precursor and occurs in unpolluted streams in only trace amounts. Concentrations of manganese in coal mine drainage usually range from 5 to 20 ppm. Aluminum is also considered an acidic precursor and is usually found in only trace amounts in unpolluted waters. Aluminum is usually a result of leaching of high alumina clays associated with the coal strata.

The exact concentrations of ferrous iron, sulfate, acidity, alkalinity, and aluminum along with flow becomes particularly important when feasibility studies are being conducted for mine drainage treatment plants.

During most acid mine drainage watershed feasibility studies the high cost of extremely careful handling of samples and exacting flow measurements are not as critical. Acid mine drainage studies have shown that many areas have a highly variable and complex hydrology. Rates of rainfall, the effects of time, surface and sub-surface mining, and geology play an important role in AMD production. The most exacting of chemical analysis and flow measurements may yield results which can only be interpreted correctly after the hydrology of the area is known. The failure to allow for adequate mixing of two streams or a discharge and its receiving stream can be the most serious error made during sampling programs.

WATER USE

The Susquehanna River Basin receives an average of 41 inches of precipitation annually. Of this an average of 20 inches evaporates and transpires, 12 to 15 inches infiltrates and eventually contributes to stream flow. An additional 6 to 9 inches is runoff, which creates a total of 24 inches of stream outflow. Ground water storage is equivalent to about 60 inches of precipitation (38).

Streams are usually given first consideration as a source of water supply, however many streams do not provide a water supply of dependable quality and quantity. Shortages can usually be prevented by the construction of dams or impoundments, but treatment for improved quality may not always be economically feasible.

Within the Susquehanna River Basin industries of food, textiles, pulp and paper, chemicals, petroleum, and primary metals are major users and consumers of water. These industries accounted for 25 percent of all manufacturing employment in the basin during 1960 (25). In 1965, a total of 597 million gallons per day (mg/d) of water was required for personal, municipal, and industrial use. Projections show that in the year 2020, a total of 2452 mg/d will be required to meet the needs of the basin (35).

People living on farms and in rural areas not serviced by public or private water utilities in 1960 were estimated at 973,000 and this number is expected to increase to 1.6 million by 1985 and to 2.2 million persons by the year 2020 (35). Anticipated agricultural water needs will increase from 32,229 mg/d in 1960 to 146,550 mg/d in the year 2020 (35). The annual yield of the basin is 8.8 trillion gallons of water which should be adequate in most areas to supply all agricultural water needs projected to the year 2020. Present livestock water use is expected to remain nearly constant until 1985 at (6.5 billion gallons per year) and then increase to 10.5 billion gallons by the year 2020. Irrigation water is expected to increase from 7.9 billion gallons per year (bg/y) in 1960 to 23.1 bg/y by 1985 and to 48.2 bg/y by 2020 (35).

Rural domestic water needs are expected to increase over 250 percent from 1960 to 1985. The estimated water used in 1960 for rural domestic water purposes was 19 bg/y compared to a projected 46 bg/y in 1985, and 88 bg/y in the year 2020 (35).

Three water service areas draw upon water from streams which are degraded by AMD to various degrees (Plate 1).

Area	Watershed Source	Projected Needs in 2020 (mg/d)
Altoona	Beaverdam Br.	48.2
Lebanon	Swatara Creek	71.3
Hershey	Swatara Creek	74.4

Altoona is further upgrading effluent from an AMD treatment plant on Kittaning Run. Lebanon and Hershey rely on tributary streams where the effects of AMD are negligable.

Out-of-basin needs are also expected to increase in the future. By the year 2020, Baltimore, Maryland is projected to use as much as 600 mg/d from the Susquehanna River for its water supply purposes (35). An additional 170 mg/d will also be diverted out of the basin by 2020. Near DuBois, Pennsylvania in the Anderson Creek Watershed of the West Branch Susquehanna, an authorized 3 mg/d is being diverted to the Allegheny River Basin (35). More detailed projections of water use and needs throughout the Basin may be referred to in numerous other publications including the Susquehanna River Basin Coordinating Committee's Appendix F--water supply and water quality, Susquehanna River Basin Study, June 1970, and those publications referenced in this report.

SEDIMENTATION

Sediment in the form of sand, silt, clay, and coal fines and other solids washed off the land surface into streams and waterways is, in addition to sewage and mine drainage, one of the nation's largest pollutants. In the United States, $125 million ($3.30 per cubic yard) are spent each year dredging about 38 million cubic yards of sediment from harbors, reservoirs, and waterways. In addition to this, it causes $100 million loss each year by reducing reservoir capacities. Streams affected by excessive sediment are also aesthetically unappealing, detract from recreational uses, and adversely affect aquatic life.

Although considerable amounts of sediment are carried from farms and strip mines the greatest single contribution of sediment per acre is urbanization, followed closely by highway construction. From these sites sediment rates approaching 20,000 times that caused by strip mines and 40,000 times that from farms have been recorded(39.1). Intolerable and costly high rates of sediment deposition also affect the Susquehanna River Basin.

Analysis of U.S.G.S. sediment-discharge measurements indicates that an average of about 3 million tons (42) (110 tons per square mile) of suspended sediment are transported annually by the Susquehanna River. Of this amount about 1.8 million tons are transported to the Chesapeake Bay annually. Individual sub-basins within the Susquehanna River Basin

have annual yields which usually range from 40 to 440 tons per square mile (42). The greatest sediment yields are derived from parts of a glaciated section of the Basin located in the Anthracite Coal Region. Information available indicates that there is currently a downward trend in sediment loads in some streams, however, urbanization may reverse this tendency.

Data from the Department of Agriculture indicates that soil erosion is a problem in 3.2 million acres (5,000 square miles) or 77 percent of the croplands in the Basin (35). Implementation of sedimentation and erosion controls should protect about 3,562 square miles of the farm lands

The major part of the Bituminous Coal Field (Plate 1), within the Susquehanna River Basin, is located in the Appalachian High Plateau physiographic province (figure 2). The North-Central Fields lie mainly in the Low Plateau physiographic province, and the remaining coal fields, the Broad Top Field and the Anthracite Fields are located in the Valley and Ridge province. The province which has the greatest range of sediment yields is the Appalachian Low Plateau province. Annual sediment loads to streams of the Basin range from 40 to 440 tons per square mile (42). Within this province sediment yields are greatest where stream valleys are narrow and steep. The Tioga River at Tioga, Pennsylvania, discharges an average of 140 tons of

DEPARTMENT OF ENVIRONMENTAL RESOURCES
TOPOGRAPHIC AND GEOLOGIC SURVEY
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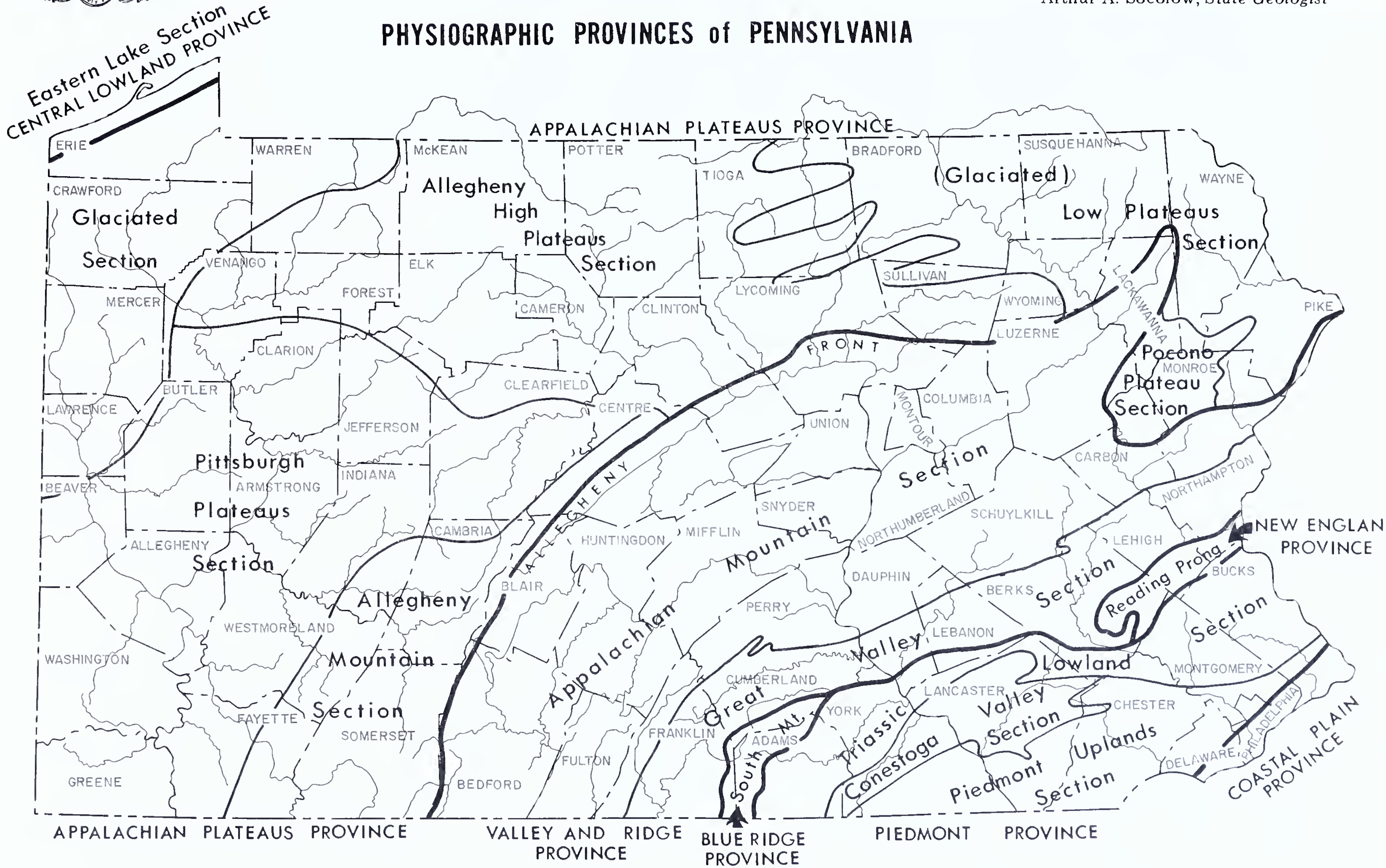
PHYSIOGRAPHIC PROVINCES of PENNSYLVANIA



sediment per square mile annually (42). Crooked Creek at Tioga, Pennsylvania discharges an annual average of 110 tons of sediment per square mile. This is the site of a proposed multi-purpose flood control dam. Downstream at Erwins, New York, the Tioga River has an average annual sediment discharge of 190 tons per year (42).

Measurements of sediment loads taken at three different stations in the Appalachian High Plateau (West Branch Watershed) indicate that 66 to 200 tons of sediments per square mile are transported annually. An average annual load of 66 tons per square mile was measured for the Driftwood Branch Sinnemahoning Creek at Sterling, Pennsylvania. An average annual load of 120 tons per square mile was recorded for the West Branch Susquehanna River at Bower Station above the Curwensville Dam (42). Contrary to what was expected sediment yields were not exceptionally high relative to other areas where strip mining has exposed large quantities of material. Apparently some fine material is transported rapidly from the area or deposited in pits and not continually flushed from stripped areas. Other watersheds in the West Branch sub-basin contribute the following average annual sediment loads per square mile. Bald Eagle Creek at Blanchard, Pennsylvania, yields an annual average of 80 tons per square mile. Marsh Creek, a tributary to Bald Eagle Creek just south of Beech Creek, yields an average annual load of 91 tons

per square mile (42). Pine Creek at Cedar Run, just downstream from Babb Creek yields an average annual of 75 tons per square mile (42). The West Branch Susquehanna River at Lewisburg has an annual average sediment yield of 77 tons per square mile (42). The four tributaries to the West Branch have a combined annual average sediment load which equals the annual average load of 77 tons per square mile measured for the West Branch at Lewisburg (42). The sediment load at Bower Station on the West Branch is 55 percent greater than the average of the four tributaries and the West Branch at Lewisburg. It is the opinion of the authors that this increase over the average is mostly due to past strip mining practices, coal processing plants and refuse disposal areas along flood plains.

Within the Valley and Ridge province average annual sediment yields range between 58 and 280 tons per square mile. The highest yielding area in this province is located east of the Susquehanna River from the Scranton and Wilkes-Barre area south to the southern limit of the Valley and Ridge province. This area contains four major anthracite coal fields which have been extensively deep and strip mined. Coal processing plants are probably the largest single contributors of sediment in the area which averages greater than 200 tons per square mile annually. Analysis of annual sediment loads per square mile and forest cover in the Valley and Ridge province indicates that a decrease of 40 percent of the forest cover can increase average

annual sediment yields from 50 to 100 tons per square mile (42). Sediment loads from watersheds within the province that are underlain by 25 percent or more limestone yield an annual average of about 25 tons per square mile (42) less than other areas with the same percent of forest cover and less limestone. The highest recorded average annual sediment load recorded in the Valley and Ridge province was 280 tons per square mile in Mahantango Creek at Dalmatia, Pennsylvania (42). Mahantango Creek is mainly affected by coal fines which wash downstream from its tributary of East Rausch Creek. Average annual sediment loads in the Juniata River sub-basin range from 62 to 90 tons per square mile. The high value was recorded in the Raystown Branch near Saxton which is downstream from several tributary streams which drain the Broad Top Coal Field.

It has been observed that 50 to 75 percent of the sediment is transported during peak flow periods. The average composition of inorganic suspended sediment was found to be 10 percent sand, 50 percent silt, and 40 percent clay. Before the Susquehanna River discharges to the Chesapeake Bay the river passes three major power dams, namely, Safe Harbor, Holtwood, and Conowingo Dams which are located 33, 25, and 10 miles upstream from the Chesapeake Bay respectively. The combined trap efficiency of the three dams is 40 percent. This accounts for an average of 1.2 million tons of sediment being deposited in the three reser-

voirs each year. The remaining average annual 1.8 million tons of sediment is transported further to the Chesapeake Bay (42).

Evidence exists that there has been a decrease in the rate of sediment discharge in the Susquehanna River Basin. Double-mass comparisons of cumulative sediment discharge versus cumulative river water discharge at Newport on the Juniata River indicates that sediment discharge rates have been decreasing since 1955. This decrease in sediment load is probably related to a sharp decrease in coal production in Huntingdon County. After 1955, coal production was only 20 to 30 percent of the previous years production (13). Analysis of reservoir-survey data for Lake Clarke, formed by the Safe Harbor Dam, indicates that the annual sediment discharge rates are decreasing. Since 1954 the Pennsylvania Power and Light Company has dredged up to 1 million tons of coal-laden deposits annually from Lake Clarke (76). From 1954 to 1970 an average of 500,000 tons of anthracite coal fines, generally less than 0.125 of an inch, were recovered by dredging operations. Dredged sediments yielded about 50 percent coal. In 1971 the Pennsylvania Power and Light Company recovered 400,000 tons of anthracite coal fines from the reservoir. In 1972 high stream flows deposited sufficient coal to permit the recovery of 350,000 tons of coal fines. Recently the decision was made by the Company to stop coal-dredging operations after 1973 due

to decreases in annual coal deposition (76). Decreased mining activities and enforcement of waste-disposal laws have contributed greatly to reducing sediment loads discharging from tributaries associated with anthracite coal production.

The bulk of the information regarding discharges of sediment in streams, also polluted by acid mine drainage, is mostly descriptive and not quantitative. However, information gathered during a hydrologic study of the Swatara Creek Basin compares sediment yields from the extensively mined Valley and Ridge part with other parts of the Basin which were not mined.

An annual average of 132,000 tons of sediment is discharged to the Susquehanna River by Swatara Creek (19). This amounts to an annual average of 230 tons per square mile with the average annual yield ranging from 33 to 600 tons per square mile. In some strip mined areas average annual sediment yields may exceed 15,000 tons per square mile per year, a yield of 500 times the normal for undisturbed and forested land. However, average annual yields of 550 to 650 tons per square mile are more characteristic of areas where strip mining has destroyed forest cover. During low flow periods the streams are nearly free of suspended sediment. As flows are increasing suspended solids increase rapidly. During the months of March and April concentrations of suspended

sediments are greatest (19).

Streams draining areas which have been stripped of their natural forest cover yield, on the average, 20 times as much sediment as unstripped areas and 2.6 times as much sediment as the Swatara Creek Basin's average. Although areas underlain and partially mined of coal occupy about 2 to 3 percent of the Swatara Creek Watershed, they account for about 7 percent of the average annual sediment yield, which appears to agree well with other areas in the Basin which were strip mined. The percent of a watershed which is stripped affects sediment yield percentages.

An analysis of average annual sediment yields from the West Branch Susquehanna River, Juniata River, Tioga River, and the Susquehanna River's (anthracite region) sub-basins indicates that above normal sediment yields are associated with all heavily stripped areas. Comparisons of sediment yields in similar areas without extensive strip mining, in the four sub-basins, indicates that a total of 20 percent of the total sediment discharged to the Susquehanna River annually is coming from areas associated with coal mining operations alone, and 13 percent or 390,000 tons of this are coal fines. About 300,000 tons are dredged from the river, and the remaining 90,000 (8) tons are transported further to the Chesapeake Bay annually. The remaining 7 percent is represented

by inorganic sediments, sand, silt, and clay which total 210,000 tons annually. It was also estimated that 1.3 million tons (43 percent) of the sediment discharged annually to the Susquehanna River is related to farming activities. The remaining 1.1 million tons (37 percent) is discharged as a result of numerous other activities in the Basin, including highway construction, housing development, logging, transmission and pipeline construction, and other forms of construction.

MINE DRAINAGE IMPACT

MINING TECHNIQUES AND AMD RESPONSES

This section will provide the reader with an account of the types of coal mining operations found in the Basin and their relationship with CMD production. In addition to this a summary of AMD conditions is presented to give the reader an appreciation of the impact AMD has locally and regionally on tributary and receiving streams throughout the Susquehanna River Basin.

Most of the AMD discharging to and affecting the Basin's streams is emanating from abandoned underground mine workings. These deep mines are developed by driving entryways ("shafts," "slopes," or "drifts") into coal bearing strata. The type of entryway chosen depends upon the orientation and elevation of the coal seams with respect to the land surface where the mine is being developed. A shaft mine is driven downward vertically into coal bearing formations when coal is not exposed near the point of mine development. Coal mined by this method often lies beneath the ground water table. Shafts are common in the Main Bituminous, Western-middle and Northern Anthracite Fields. Slopes are entryways sloping downward to intercept a coal seam. A drift entryway is usually driven toward the rise of an outcropping coal which tilts or dips slightly. In the Anthracite Field so called "tunnels" or large haulageways are driven

with a slight rise, to provide gravity drainage, into numerous coal seams which dip downward and return to the surface, oriented and formed like the letter "U".

While coal is being removed from mines infiltrating ground water is removed by gravity drainage or pumping. Active shaft and slope mines are usually, but not always, pumped to avoid inundation of recoverable coal. If a coal basin lies above natural surface drainage a water level tunnel can be driven into the lowest seam mined to provide gravity drainage. Drainage from drift mines is usually accomplished by gravity discharge, although some pumping or siphoning may be required from local rolls and low spots. Pumping is usually required when mine development cannot proceed toward the rise of the coal or is below the regional ground water level. Drift mines are a major and continuing source of CMD in the Basin because, when abandoned, they do not fill with water and tend to discharge a quality of water which seemingly never shows improvement. Numerous mine drainage discharges from drifts in the Main Bituminous Field which were developed in stratigraphically equivalent coal seams, (and abandoned decades apart) have similar water quality.

In several cases, especially in the Anthracite Fields, abandoned shaft and slope mines are filled by infiltrating water which inundates mine

workings and eventually overflows to the surface. Natural inundation of iron disulfide minerals has been beneficial to the quality of drainage from mines. Decreasing amounts of mine drainage are also caused by rejected ground water recharge. Large overflows in the (Duryea, Old Forge) anthracite region have shown water quality improvements since they first broke to the surface in 1961 (70). These outfalls, however, still discharge MD with a water quality which cannot be tolerated and abatement will be required. Large water level tunnel discharges are also some of the largest single and continuing sources of AMD. Tunnels like the Jeddo, Audenreid, and Green Mountain drain large coal basins containing numerous disulfide mineral seams. Natural inundation of the entire mine workings does not occur and some of the most favorable conditions for the production of AMD exist.

Surface mines presently consist of large strip mine operations which use large draglines and front-end loaders for overburden removal. When further removal of coal becomes uneconomical by conventional strip mining methods, large augers are sometimes used to bore horizontally into the exposed coal seam in the highwall. Surface mines may be drained by gravity or pumped, depending upon the elevation of the surface drainage in the area. In addition to removing any ground water

that enters surface mines, steps must be taken to divert surface drainage so that it does not enter the mine workings. Discharges from surface mines are often intermittent, generally occurring during and immediately after periods of moderate to heavy precipitation. In areas disturbed by surface mining, runoff may be trapped as impoundments or pools in improperly restored strip pits. These pools contain high concentrations of dissolved salts and are reservoirs of potential mine drainage pollution. During periods of high runoff, they may overflow and release concentrated "slugs" of mine drainage pollution to receiving streams. Many drain slowly into the bottom and sides of the entrapment to emerge in the form of seepage down slope from the mining operations or infiltrating into and through deep mine workings, thereby augmenting deep mine flows with high concentrations of dissolved solids.

Pollution also emanates from refuse piles associated with mining operations. Refuse piles are often spread over large areas intentionally or just as a result of spillage from transportation of the material to disposal areas. Quite often this waste material contains minerals which yield, upon dissolution, extremely high concentrations of dissolved solids during brief high rainfall periods. Information now exists on the effects of mine refuse on water quality throughout the Basin which is reported in the sub-basin's AMD descriptions.

The following summarizes the severity and distribution of MD sources in the Basin

1. Deep mine gravity discharges in the Anthracite Field are less numerous than in other areas, but contribute a much larger acid loading per discharge.

2. Anthracite mine pool (deep mine) overflows show some water quality improvements with time but still remain intolerable.

3. Anthracite strip mines are a less significant source of AMD than bituminous strip mines, however, both types can increase deep mine discharges.

4. In all coal fields abandoned deep mine discharges are a more significant source of AMD than other primary sources. However, on an individual watershed basis other sources, on occasion, may be as significant.

5. The greatest source of AMD in the Basin are the abandoned gravity deep mine discharges in the bituminous field. These discharges show practically no water quality improvement with time, and are the most serious problem in the Basin.

6. Coal refuse is a significant source of AMD in some watersheds of the Main Bituminous and Anthracite Fields.

A summary of the types of AMD production and their effects on streams is provided in Tables 2 and 3 to give the reader a brief account of the relative influence of the factors mentioned above. A more detailed discussion of sources of mine drainage and their effects on stream quality may be found in the AMD sections of the indivudual sub-basins.

TABLE 2 – Sources of Mine Drainage by Watershed

Watershed	Deep Mines	Strip Mines	Coal Refuse
	PERCENT OF COAL MINE DRAINAGE CONTRIBUTED BY:		
WEST BRANCH SUSQUEHANNA RIVER			
Upstream from Chest Creek	28	2	70
Chest Creek	34	30	36
Reach from Chest Creek to Clearfield Creek	60	35	5
Anderson Creek	50	40	10
Clearfield Creek	75	20	5
Clearfield Creek to Moshannon Creek	70	20	10
Moshannon Creek	70	20	10
Moshannon Creek to Sinnemahoning Creek	60	30	10
Sinnemahoning Creek	70	20	10
Sinnemahoning Creek to Bald Eagle Creek	75	20	5
Bald Eagle Creek to Beech Creek	60	20	20
Bald Eagle Creek to the Mouth of West Branch	80	15	5
JUNIATA RIVER			
Little Juniata River	0	0	0
Frankstown Branch Beaverdam Branch	0	0	0

TABLE 2 cont.

Watershed	PERCENT OF COAL MINE DRAINAGE CONTRIBUTED BY: Deep Mines	Strip Mines	Coal Refuse
Burgoon Run	0	0	0
Sugar Run	90	10	0
Raystown Branch			
Six Mile Run	75	20	5
Shoup Run	75	20	5
Sandy Run	80	20	0
Great Trough Creek	90	10	0
Augwick Creek			
Roaring Run	75	20	5
TIOGA RIVER			
Morris Run	75	20	5
Coal Creek	75	20	5
Bear Creek	75	20	5
MAIN AND NORTH BRANCH SUSQUEHANNA RIVER			
Lackawanna River (Upper and Lower)	70	20	10
Lackawanna River to Nescopeck Creek	80	20	0
Nescopeck Creek	90	10	0
Catawissa Creek	90	10	0
Shamokin Creek	80	20	0
Mahanoy Creek	75	15	10
Rausch Creek	75	15	10
Wiconisco Creek	97	3	0
Swatara Creek	70	15	15

MILES OF STREAM IN WHICH WATER QUALITY
IS SIGNIFICANTLY DEGRADED BY MINE DRAINAGE

Bituminous Region	Sub-Basin	Miles of Main Stream	Miles of Tributary Streams	Total
West Branch Susquehanna	Headwaters (Upstream from Chest Creek)	31	43	74
	Chest Creek	0	7	7
	Anderson Creek	10	10	20
	Clearfield Creek	61	87	148
	Moshannon Creek	52	57	109
	Sinnemahoning Creek	51	61	112
	Beech Creek	30	25	55
	Babb Creek	16	13	29
	Loyalsock Creek	8	0	8
	West Branch & Minor Tribs. Chest Creek to Sinnemahoning Creek	95	70	165
	West Branch & Minor Tribs. Sinnemahoning Creek to Mouth	70	14	84
	Basin Sub-Total	424	387	811

TABLE 3 cont.

Basin	Sub-Basin	Miles of Main Stream	Miles of Tributary Streams	Total
Juniata River	Beaverdam Branch	3	19	24
	Little Juniata	0	1	1
	Raystown Branch	0	24	24
	Aughwick Creek	0	12	12
	Basin Sub-Total	3	58	61
Tioga River		29	12	41
Anthracite Region	Lackawanna River	31	2	33
	Nescopeck Creek	18	29	47
	Catawissa Creek	39	8	47
	Shamokin Creek	35	11	46
	Mahanoy Creek	52	13	65
	Rausch Creek	17	13	30
	Wiconisco Creek	12	5	17
	Swatara Creek	30	27	57
	Susquehanna River and Minor Tributaries	22	10	32
	Basin Sub-Total	256	117	373
Susquehanna River Basin	TOTAL	712	592	1304

SUMMARY OF STREAM POLLUTION
IN THE
SUSQUEHANNA RIVER BASIN

SUMMARY OF BITUMINOUS REGION

West Branch Susquehanna River

The bituminous region is drained by the Juniata, Tioga, and West Branch Susquehanna River sub-basins. The West Branch Watershed is the largest of the three sub-basins and drains 6,900 square miles. This sub-basin contains 3,720 square miles of land underlain by bituminous and some semi-anthracite coal. Extremely severe AMD pollution exists in sub-watersheds which are entirely underlain by high disulfide coals and associated strata which produce low natural alkalinities. The largest single source of AMD in the sub-basin is the abandoned drift mine. High disulfide coal seams worked are: the Clarion, Brookville, and Lower Kittanning, and in fewer cases the Lower Freeport. Locally, coal mine refuse is also an important contributor of AMD. Unreclaimed strip mines augment deep mine discharges and do account for additional dissolved solids. Quite often strip cuts were made on the downdip side of seams previously deep mined. Deep mines which were opened by stripping frequently drain acid mine waters into strip mine spoil, where acidity often increases. Strip mines are usually a more serious problem when they cut into deep mine workings or augment infiltration to deep mine workings. This is a common problem in the West Branch and adds to com-

plications in designing effective abatement measures other than treatment.

Upstream from Clearfield Creek, the West Branch and its tributary streams have shown some water quality improvements in past years. However, AMD is still a major problem in some small watersheds and in certain portions of larger watersheds. The West Branch, upstream from Chest Creek, is primarily affected by mine refuse and abandoned "B" seam deep mine discharges. Deep mines are a continual source of AMD pollution in the West Branch, but apparently do not affect water quality as severely as occasional acid slugs from coal refuse in the headwaters region of the West Branch. Chest Creek is affected by AMD in only a few of its tributary watersheds. Sources of acid in Chest Creek are abandoned deep mines and coal refuse. Other than a few watersheds above Clearfield Creek which have small AMD loadings, Anderson Creek is the only watershed with significant amounts of AMD. This comes mainly from clay strip mines and some deep mines.

Clearfield Creek is the uppermost large and continual source of AMD discharging to the West Branch. Between 59 and 61 thousand ppd acid are discharged to the West Branch by Clearfield Creek. Most AMD in the Clearfield Creek Watershed is emanating from abandoned deep mines. Moderate size discharges of AMD can be found from the headwaters to the mouth of Clearfield Creek. Most small discharges of AMD in the

Clearfield Creek Watershed are offset by natural alkalinity. However, several moderate to large sources of AMD in the center of the watershed seriously degrade Clearfield Creek to its mouth. Muddy Run and Japling Run discharge about 50 percent of the AMD recorded at the mouth of Clearfield Creek. Immediately up and downstream of these major discharges, Clearfield Creek is affected by other moderate size discharges of AMD caused equally by deep mines, strip mines and coal refuse piles.

The reach of the West Branch from Clearfield to Moshannon Creek contributes numerous discharges of AMD to the West Branch. These range from 3,000 to 8,000 ppd acid, with Alder Run contributing the largest acid load of 15,000 ppd. The total contribution of AMD to the West Branch in this reach is 71,000 ppd. Many severely degraded tributaries in this reach are underlain by highly mineralized strata, rich in sulfides. The contribution of AMD in this reach is surpassed only by Moshannon Creek and will be difficult to fully abate.

Moshannon Creek is the greatest single contributor of AMD to the West Branch. Small to moderate amounts of AMD originate in the headwaters and lower reaches of this watershed, however, the greatest contributions emanate from the central part of the watershed. From Bear Run to Weber Run, Moshannon Creek receives large discharges of AMD primarily from large interconnected "B" seam deep mines. These are a

continuing source of high volumes and high concentrations of AMD. At its mouth Moshannon Creek contributes 95 to 135 thousand ppd of acid to the West Branch. Complete abatement of AMD in the Moshannon Creek Watershed will be extremely difficult and costly. Abatement of AMD in streams tributary to the West Branch, from Clearfield Creek to Moshannon Creek, would greatly improve water quality in this reach, as well as downstream.

Contributions of AMD in the reach of the West Branch between Moshannon and Sinnemahoning Creeks are moderate to small. Abatement of AMD in this area is recommended for the benefits small tributary streams in this reach will accrue. No significant increases of AMD are noticed in this reach of the West Branch.

The Bennett Branch Sinnemahoning Creek is acid from Moose Run to its confluence with Sinnemahoning Creek, which is also acid to its mouth due only to the effects of its Bennett Branch tributary. The Bennett Branch discharges 23,000 ppd acid to Sinnemahoning Creek (72). Four tributaries to the Bennett Branch contribute more than 1,800 ppd acid. Primary source of mine drainage, as elsewhere in the West Branch, are abandoned deep mine discharges and some mine refuse dumps.

Recent studies in the Kettle Creek area indicate that 44,000, 11,600, and 32,500 ppd acid (50) are contributed to the West Branch from

Kettle Creek, Milligan Run, and Crowley Run (tributary of Cooks Run) respectively. Some of this acidity is thought to be due to ground water because sulfate loadings were relatively low and nearly equivalent to acid loadings. Also, other data sources indicate lower AMD loadings. The primary sources of AMD in the Kettle Creek area are abandoned deep mines.

Bald Eagle Creek with its high alkaline load contributes about 130,000 ppd to the West Branch (72). Under normal flows this alkalinity neutralizes all of the West Branch's acidity. Bald Eagle Creek has one tributary, Beech Creek, which is significantly affected by AMD. Most tributaries in the northwestern part of the Beech Creek Watershed are acid. Under average conditions, 88 percent of the acid entering Beech Creek (43,000 ppd) is contributed by the North Fork and Sandy Run sub-basins (18). Major discharges of AMD emanate from abandoned deep mines. Some high acid discharges come from coal refuse piles and strip mines. At its mouth Beech Creek contributes 13,500 ppd to Bald Eagle Creek. This acid is completely neutralized by Bald Eagle Creek's alkalinity.

In the remaining part of the West Branch, AMD only affects a few small tributary areas in Pine and Loyalsock Creeks (72). Babb Creek, a tributary in Pine Creek's northern watershed area, is affected

by AMD entering Wilson Creek and Stony Fork. Abandoned deep mine discharges are the major sources of AMD. AMD discharged to Babb Creek does not pollute its receiving stream, Pine Creek. Little Pine Creek, a tributary in Pine Creek's southern watershed area, is affected by two tributaries, English Run and Otter Run. Both tributaries lie adjacent to one another and are of approximately the same size. Both English and Otter Runs are primarily affected by AMD discharged from abandoned deep mines. Most of these mines may be sealed, which should abate the bulk of the AMD entering both tributaries. Strip mines discharge smaller amounts of AMD to Otter and English Runs. English and Otter Runs discharge 4,600 and 3,500 ppd acid (16) to Little Pine Creek respectively.

Loyalsock Creek is only slightly affected by AMD from the Village of Lopez to Forksville. At Forksville, Little Loyalsock Creek's alkalinity overcomes this acidity. AMD emanates from two tunnels yielding 2,000 ppd acid (72). In 1973 the DER initiated an AMD feasibility in this watershed.

Juniata River

The Juniata River Basin drains an area of about 3,400 square miles, nearly all of which is located in the Valley and Ridge Province, which contains the Broad Top Coal Field. The northwestern part of this

watershed drains the southeastern edge of the Allegheny Plateau that is underlain by an edge of the Main Bituminous Coal Field.

Two major tributaries of the Juniata River Basin, which drain the Allegheny Plateau, Little Juniata River and Frankstown Branch, are affected by AMD discharging primarily from abandoned deep mines. Bell Gap Run, a tributary of the Little Juniata River is only mildly polluted. This watershed received extensive surface restoration by the DER (68). The Beaver Dam Branch, a tributary of the Frankstown Branch, has two of its tributaries affected by AMD. These tributaries, Burgoon Run and Sugar Run are the only tributaries severely affected by AMD emanating from the Main Bituminous Field. The DER's AMD treatment plant (68), located in the Horseshoe Curve near Altoona, is providing an economic solution for Burgoon Run's AMD problem by treating this AMD and further upgrading some of this effluent for the public water needs of Altoona. Sugar Run is not as severely polluted, but does contribute 630 ppd acid to Beaver Dam Branch. One abandoned deep mine accounts for nearly all of Sugar Run's AMD.

The Raystown Branch and its tributaries along with Augwick Creek, to the south, drains the 81 square mile Broad Top Coal Field. The abandoned deep mine is the greatest contributor of AMD in the Broad Top Field. Discharges occur in the form of mine pool relief

borehole overflows in addition to other artesian and gravity discharges. Shoup Run, Six Mile Run, and Sandy Run, tributaries of the Raystown Branch, are polluted by AMD. Occasional small amounts of AMD contributed to the Raystown Branch by these tributaries do not degrade water quality of the Raystown to any appreciable extent. Augwick Creek's tributary, Sideling Hill Creek is initially affected by AMD from its tributary, Roaring Run, but the natural alkalinity from ground water provides an alkaline discharge to Augwick Creek.

Mine sealing and alternative treatment are being considered for abatement of the Broad Top Field's AMD. These procedures are presently being evaluated by the DER.

Tioga River

The Tioga River Basin drains a 1,391 square mile area of the Allegheny Plateau Province (figure 2), of which 690 square miles lie within Pennsylvania. The headwaters of the Tioga River are affected by AMD emanating from bituminous coal beds equivalent to coal beds of the Main Bituminous Field to the west (Plate 1). Three tributaries of the Tioga River (Morris Run, Coal Creek, and Bear Creek) drain this coal basin and are extremely degraded by AMD emanating from abandoned deep mines. Coal Creek,

located in the center of the Basin, drains an effectively larger area than either Morris Run or Bear Creek. Under low flow conditions Coal Creek contributes 70 percent of all AMD entering the Tioga River. Morris Run, Coal Creek, and Bear Creek, according to U. S. Army Corps of Engineers' data, contribute an average of 17,700, 21,000, and 3,750 ppd acid respectively to the Tioga River.

Abatement of AMD in the Tioga River Basin is important due to federal interest in constructing multi-purpose dams which will provide 0.5 million recreation days each year. An evaluation of the effectiveness of various forms of abatement is currently being studied in the Tioga River Basin. Studies are also being conducted to evaluate maximum levels of AMD which can be tolerated for the intended utility of the Tioga River Basin's waters.

SUMMARY OF ANTHRACITE REGION

The anthracite fields are geographically separated into four fields. From north to south they are the Northern, Eastern Middle, Western-Middle, and Southern Fields(Plate 1). The Northern Field is drained by the major tributary to the Susquehanna, the Lackawana River, which enters the Northern Field from the northeast near Forest City. The Lackawanna River (above Carbondale) receives several large discharges from isolated mine pools. These pools contribute little acidity and have a small overall affect on the River's water quality except for the increase in dissolved solids. The Lackawanna River, however, receives several mine pool overflows near its mouth which are the greatest contributors of AMD in the Susquehanna River Basin. These discharges, Duryea and Old Forge, have a combined discharge of 90,000 ppd acid (70) and degrade the Lackawanna River for a distance of about 2 miles, from its mouth. The Susquehanna River, however, retains its alkaline condition, but is seriously degraded by the additional dissolved salts. Downstream the Susquehanna River receives additional large discharges of AMD from Solomon, Nanticoke, and Newport Creeks. Solomon Creek is affected by drainage from two major discharges referred to as the South Wilkes-Barre boreholes (three 36-inch boreholes) and the Buttonwood Airshaft. These openings commonly discharge up to 260,000

and 110,000 ppd acid to Solomon Creek respectively (70). Water quality is expected to improve somewhat over the next few years, but will still remain below desired levels unless some abatement measures are implemented. New boreholes are being placed to reduce mine pool circulation, thereby reducing AMD formation. The Askam borehole discharges an average 71,000 ppd acid to Nanticoke Creek (70). Farther downstream the Susquehanna River receives its last major contribution of AMD from Newport Creek which drains the southwest part of the Northern Field. Newport Creek currently discharges an average of 165,000 ppd acid (70) to the Susquehanna River. About half of this is pumped from an active deep mine.

Two tributaries drain the Eastern-Middle Field, Nescopeck, and Catawissa Creeks. Both streams are primarily affected by discharges from water level tunnels driven expressly for drainage purposes. Nescopeck Creek receives AMD from one of the largest discharges of MD in the Basin, the Jeddo Tunnel. The Jeddo Tunnel discharges an average 100,800 ppd acid to Little Nescopeck Creek, a tributary of Nescopeck Creek. Two other discharges of AMD affect Black Creek, another tributary of Nescopeck Creek. The Gowen and Derringer Tunnels contribute over 7,000 ppd acid to Black Creek. Nescopeck Creek contributes over 90,000 ppd acid to the Susquehanna River (70). Under normal flow conditions the Susquehanna River remains alkaline below its confluence

with Nescopeck Creek. However, following prolonged dry or low-flow periods, the Susquehanna may be acid from Newport Creek, to a short distance below Nescopeck Creek.

Catawissa Creek is affected primarily by discharges from the Green Mountain water level tunnels each of which contribute about 5,400 ppd acid to Catawissa Creek. These tunnels are being considered for sealing by the DER. The largest discharge of AMD to Catawissa Creek emanates from the Audenreid water level tunnel, which contributes an average 52,900 ppd of acid (70). Sealing of the Audenreid and Green Mountain Tunnels would improve the water quality of Catawissa Creek substantially (63). The Cox #1 and #3 tunnels discharge to Tomhicken Creek, a tributary of Catawissa Creek, and contribute an additional 3 to 4 thousand ppd acid (70). Treatment of these discharges alone will be prohibitively expensive and sealing remains the best alternative to abate most of this AMD.

The Western-Middle Field is drained by Shamokin and Mahanoy Creeks which are affected by AMD in their headwaters. It is reported (72) that Shamokin Creek is affected by eight major AMD discharges. North Branch Shamokin Creek, Quaker Run, and Carbon Run, tributaries receive AMD which emanates from drift entries. All major discharges of AMD in the Shamokin Creek Watershed total 33,400 ppd acid (72). Most of this AMD reaches the Susquehanna River and is not neutralized by natural

alkaline reserves. Abatement of AMD in the Shamokin Creek Watershed will involve extensive surface restoration and mine sealing where feasible.

Mahanoy Creek drains the southern part of the Western-Middle Anthracite Field. Mahanoy Creek is acid in its headwaters but does contribute over 3,000 ppd alkalinity to the Susquehanna River (72). Tributaries of Mahanoy Creek which contribute significant amounts of AMD are: Waste House Run, North Mahanoy Creek, and Zerbe Run. Pump discharges and gravity overflows contribute most of the AMD entering Mahanoy Creek. All significant sources of AMD contribute a total of 67,400 ppd of acid to Mahanoy Creek (72).

The Southern Field is drained by three major tributaries that are polluted with AMD in their headwaters. From north to south these tributary streams are: Rausch Creek (a sub-watershed of Mahantango Creek), Wiconisco Creek, and Swatara Creek. Rausch Creek is primarily affected by four discharges of AMD, each in excess of 1,000 ppd. The Markson Columnway, Valley View Tunnel, Buck Mountain Drift, and Good Spring Number One Airhole discharge an average 4,150, 2,500, 1,650, and 1,050 ppd of acid to Rausch Creek, respectively. Currently the DER (45) is completing repairs on a lime neutralization treatment plant which was damaged by tropical storm Agnes. This plant will abate most of Rausch Creek's AMD.

Wiconisco Creek is affected by gravity discharges of AMD from several mine tunnels. Alkaline discharges completely neutralize acid discharges downstream from the confluence of Bear and Wiconisco Creeks. Several miles upstream from Bear Creek, Wiconisco Creek is acid to its headwaters. Wiconisco Creek discharges 6,700 ppd alkalinity to the Susquehanna River (29). The DER is currently doing surface reclamation work in the Wiconisco Creek Watershed (57).

Swatara Creek, which drains an area of 597 square miles, is only affected by AMD in its extreme headwaters. In the northeastern part of the basin Swatara Creek is severely degraded by three major sources of AMD (19). They are: 1) an average 2,000 ppd acid seeps continuously from a refuse dump, 2) an average 591 ppd acid discharge from a rock tunnel, and 3) an acid mine pool overflow of 446 ppd (average). The central part of the basin's worst sources of pollution are abandoned deep mines and their associated overflows, which average nearly 6,000 ppd or 61 percent of the total AMD (7). Coal mine refuse is the second largest contributor of acid to the area, with an average discharge of 3,100 ppd or 32 percent of the total AMD emanating from the central area. The northwestern part of the basin (2) is mainly affected by deep mine discharges from Rowe Tunnel, Rausch Creek Tunnel, several smaller deep mine discharges, and seepage from mine refuse. Sediment discharges

are also a problem in the northwestern headwaters of Swatara Creek. Currently the DER is doing extensive surface restoration work in the Swatara Creek area (45). Abatement here and elsewhere in the Anthracite Region will be costly on a per acre basis compared to other areas in the Basin.

BENEFITS

An account of benefits derived from cleaning polluted streams and restoring stripped lands can be clarified by listing the various forms of utility returned to the streams and land as well as discussing the damages AMD causes. The immediate effect AMD has on surface and sub-surface drainage (springs) is, in most cases, the lowered pH, reduced natural alkalinity, increased total hardness, iron, manganese, aluminum, sulfate, and other dissolved and suspended solids. Estimates of dollar values of the resulting damages these conditions create are discussed in following sections. In addition to this, monetary benefits or dollar evaluations of uses returned to unpolluted streams and reclaimed and vegetated lands are discussed below.

The most pollution sensitive water use is fishing. Damage to fish and fish food organisms is usually caused by high concentrations of acid, iron, sulfate, and the deposition of a smothering blanket of precipitated iron salts in stream beds. In addition, zinc, copper, and aluminum have been measured in lethal concentrations in some discharges. The toxicities of these elements are compounded by synergism among several of them (27). Because of the complex nature of mine drainage, it is difficult to accurately measure the toxicity to aquatic life of any single chemical component.

The destruction of aquatic life and the discoloration of water and

stream bottoms by precipitates combine to make the streams and impoundments aesthetically unappealing to all persons. The loss of recreational value due to MD and denuded lands far exceeds previous FWPCA estimates by amounts not attributed to inflation alone. Although coal continues to be a valuable natural resource its extraction from the ground, for nearly centuries, has created an accumulating loss of other natural resources and commodities. These losses can no longer be accepted as other human needs continue to increase.

Human needs go beyond aesthetic and recreational interest. CMD also has a definite, adverse effect on the use of streams for industrial, municipal, and some agricultural water supply. In water treatment plants, high acidity and low pH may result in adverse effects on chemical coagulation, softening, and corrosion control. Telephone and electrical services are seriously hampered when AMD comes into contact with buried transmission lines (59). Corrosion of lead jackets and loss of conductivity are caused by acid. Corrosion control is the major problem of most industrial users (5), but is somewhat difficult to evaluate.

Both iron and manganese create serious problems in public and in some industrial water supplies. Iron and manganese salts stain plumbing fixtures and laundry and interfere with some industrial processes. Iron supports the growth of filamentous bacteria,

which restricts and even stops the flow of water in distribution lines. Some sulfate compounds and the end products of their reaction with calcium and magnesium carbonate (the principal constituents of the alkalinity of many streams) produce permanent hardness in water (27). Hardness is objectionable in public supplies, particularly because consumers are forced to use more soap for cleaning purposes or pay for softening. Permanent hardness in boiler feed water forms scale, which cuts down on heat exchange efficiency of boilers (5). The greatest single use of water for industry is for cooling.

The use of mine drainage for crop irrigation tends to increase the acidity of normally acid soils in the Basin. It may also cause a chemical reaction in the soil adversely affecting its beneficial properties. The exact effects, however, are still to be determined and Pennsylvania State University agronomists are currently studying this subject (48).

Livestock and wildlife use is also impaired by mine drainage effects. From interviews with farmers (47) it was learned that milk production is seriously affected when cows only have water containing mine drainage indicators. An evaluation of these damages is also difficult.

Dollar values for damages and benefits are listed only for those categories where studies or supportive information make realistic estimates possible. In some cases where written documents were not

available, estimates were given only if information was provided by some of the best authorities on the subject. All benefit dollar values given do not take into account the generation of an additional $3 to $4 of business for each immediate benefit dollar (20). This is referred to by some economists as the multiplier effect.

HUNTING AND FISHING

The United States Department of the Interior's Bureau of Sport Fisheries and Wildlife conducted its fourth National Survey of Fishing and Hunting in 1970 (39). Information gathered during this survey was utilized to estimate benefit costs for various forms of recreational activities which are derived from clean streams and reclaimed lands. Portions of the survey's findings are presented below.

In 1970, about 128 million persons (39) participated in various forms of recreational activities in the United States. Fishing and hunting ranked very high. The survey determined that almost 55 million persons spent 779 million recreational days fishing and hunting. As defined by the 1970 survey, "a recreational day is a day any part of which was spent fishing, hunting, or involved in other forms of recreational endeavor." During 1970 some 30 million fresh water fishermen spent 3.7 billion dollars on 592 million recreational days, or $6.30 per day. Small game hunters, numbering 11.67 million, spent nearly 1 billion dollars on 124 million recreational days, or $7.62 per day. About 7.77 million big game hunters spent nearly 1 billion dollars on 54.5 million recreational days, or $17.47 per day. Other recreational activities included 411 million days bird watching, 39 million days photographing wildlife, and 337 million days hiking (39).

The Pennsylvania and New York State region was determined by the Fourth National Survey to have the lowest percentage of its residents fishing compared to other regions in the United States. The percent of people fishing in nine different areas in the United States ranged from 14 to 31 percent with a mean of 22 percent. The Pennsylvania-New York area also had the lowest percentage of its residents classified as hunters. Only 6 percent of this area's population hunted. Percentages throughout the United States range from 6 to 17, with a mean value of 10.3. These low percentages may indicate that increased recreational facilities are needed and will be utilized when available by the areas potential hunters and fishermen.

The results of an analysis (20) of small game hunting conducted in Pennsylvania was found to agree very well with the results of the Fourth National Survey. Pennsylvania's survey estimated an expenditure of $96 per year per person compared to the National Survey's $81 per person per year. The National Survey's value, which is 16 percent lower than the Commonwealth's also reflects to some extent inflationary trends since 1970. It was determined from the National Survey's big game evaluation and Pennsylvania's small game survey that 216.4 million dollars (20) were spent hunting big and small game in Pennsylvania by residents and non-residents (numbering 2.0 million during 1972). Pennsylvania has an area

of 45,333 square miles. Eighty(80) percent or 36,266 square miles (23.2 million acres) is potential game land. For each acre of game land, an average of $9.32 was spent by Pennsylvania area sportsmen. This value will be utilized to estimate the value of one acre of reclaimed land for hunting benefit purposes. This value is approximately equivalent to the expenditures made by big and small game hunters during a one-year period for clothing, food, lodging, auto expenses, licenses, guns, ammunition and many other miscellaneous items.

Reclamation of strip mined land will also provide increased hunting potential and benefits in adjacent lands. However, these benefits will not be accrued for higher benefit cost ratios since unreclaimed strip mines do support some wildlife activity. Therefore, fair estimates of benefits derived from reclaiming one acre of land will not be considered for adjacent areas.

Estimates of additional fisherman days (27) were developed from information obtained from the Pennsylvania Fish Commission. A value of $6.30 per day was applied to each additional fresh water fishing recreational day, a dollar value determined by the Department of the Interior's Fourth National Survey (39). Estimates of fishing benefits were derived for streams which can be realistically restored.

RECREATION AND AESTHETICS

The adjective aesthetics may not convey the exact same meaning to each individual, but it does relate in all cases to a person's general perception and appreciation of nature and its beauty. Aesthetics play a very real, universal, and important role in everyone's lives. Antique shops, mass urban to rural movement, art museums, national forests, and parks all testify to our common everyday interest in aesthetics. During summer months, tourist activities in the western United States and other localities are alive with interest centered around the aesthetic enjoyment of nature, which stands opposed to mankind's mechanical alteration or defacement of the environment.

A purely objective monetary evaluation of aesthetics is extremely difficult, and perhaps never to be achieved, without a few assumptions being made. There may easily be as many different monetary evaluations of aesthetics as there are concerned taxpayers and voters. Aesthetics can best be evaluated using known dollar relationships with the pure enjoyment of nature. This in turn can be associated with the price citizens are willing to pay to restore our lands and waters to an aesthetically appealing condition.

A partial relationship was found by the Fourth National Survey conducted by the Department of the Interior in 1970 (39). Three forms of

recreational activities were surveyed, nature walks or hiking, wildlife photography, and birdwatching. During 1970, throughout the United States, 26.9 million persons spent 337 million recreational days nature walking. About 4.52 million persons spent 37.83 million days photographing wildlife. Another 6.8 million persons spent 411.4 million recreational days birdwatching. All of these recreational activities are directly associated with the aesthetic enjoyment or the perception and appreciation of nature. These activities all require expenditures for equipment, transportation, and food. The expenditure for these items is approximately equivalent to an average $80 per year spent by persons involved in other forms of outdoor recreational activities. On a national basis at least 786.3 million recreational days were spent during 1970 on purely aesthetic activities. This compares with only 178.6 million recreational days spent big and small game hunting during 1970. The larger number of recreational days spent on aesthetic type activities is mainly due to the lack of time restrictions or open seasons. Aesthetic type activities can be enjoyed in many ways 12 months of the year, as opposed to about two months for big and small game hunting. This fact increases the aesthetic value of one acre of reclaimed land just on the basis of time alone. It was determined by a survey (20) held in Pennsylvania that this State agrees very well with hunting interest and expenditures found on a nationwide basis by the Fourth National Survey. It is assumed that aesthetic activities in

Pennsylvania also agree well with the Fourth National Survey's findings. On this basis, using the Fourth National Survey's $80 per year per person expenditure, 791 million dollars are estimated to have been spent during 1970 by all persons actively pursuing aesthetic activities in Pennsylvania. This amounts to $30 per acre per year or .08¢ per acre per day assuming that 90 percent of Pennsylvania's area can be utilized for aesthetic enjoyment.

A value of $30 per acre per year may be an underestimation of the yearly aesthetic value of one acre of reclaimed land since it was derived only from persons actively pursuing aesthetic activities. This value does not consider persons passively interested in an area's natural beauty. Such individuals may be traveling through an area or spending a brief period of time near devastated lands for other purposes. Reclaimed lands will also greatly enhance adjacent areas which presently have their value depreciated by unreclaimed lands. Restored lands also cause reductions in sediment loads in streams, and the precipitation of unsightly salts, which detracts from the aesthetic appeal of most streams.

Stream non-fishing recreational improvement benefits were computed on a basis similar to land improvement aesthetic benefits. A polluted stream is innately unappealing to most people. As a consequence, little recreational uses occur on or in the vicinity of the banks of polluted

streams. Land values along the banks of polluted streams are far below similar stream bank land values for non-polluted streams. The recreation potential is minimal as long as the stream is polluted. This is evidenced by the number of recreational (second) homes on non-polluted verses polluted streams. The West Branch region is a very good example. Recreational homes dot the banks of non-polluted streams such as the First Fork Sinnemahoning, Loyalsock, and Pine Creek. Conversely, there are very few cabins located on the polluted parts of the West Branch, Clearfield and Moshannon Creeks. A non-fishing recreational improvement value of $30 per acre per year has been assigned to stream bank land. This value is the same as that applied for restoration of strip mined land. This improvement value encompasses such diverse benefits as improved land values, improved land use for recreation activities such as camping, hunting, and other nature enjoyment pursuits. The abatement of AMD pollution in the Basin's streams is expected to greatly improve the recreational potential of the stream bank lands.

It has been assumed that this improvement benefit would apply to all lands within 600 feet of a reclaimed stream. This translates to 145 acres of land per mile of reclaimed stream. The applicable benefit value would then be approximately $4,400 per mile of reclaimed stream

per year. This benefit was applied to each mile of reclaimed stream in each subwatershed.

AGRICULTURE

There are numerous examples of strip mined land being restored specifically for agricultural use. The potential agricultural value of an acre of land depends upon many factors. These include rainfall rates, soils, material nutrients and soil reaction with regard to pH, slope, drainage or moisture capacity, and general agricultural economics. A very small percent of the land in the Anthracite and Broad Top Coal Fields is overlain by soils which are suitable for agricultural purposes (60, 48). Special soil treatment could, however, increase this percentage factor not only for these areas but for others in the West Branch Susquehanna and the Tioga River Basin's coal beds as well. The least productive areas are usually forested or poor pasture land. The West Branch Susquehanna area is, relatively speaking, the most productive area and has many acres of land suitable for corn, grain, vegetables and pasture. The Tioga River Basin is not as productive as the West Branch sub-basin but does have areas suitable for hay, pasture, potatoes, small grain, and buckwheat.

Historically, crop dollar values have fluctuated widely. Corn, alfalfa, wheat, and oats, for example, currently have gross average annual values per acre of $125, $100, $80 and $75 respectively (60). If crops are used as feed for beef, pork, eggs, poultry and dairy products, for example,

this increases the average annual gross dollar value of about $100 per acre (60). Farmers (66) and Pennsylvania State University College of Agriculture experts interviewed both agree that an average annual gross value of $100 per acre represents a realistic and probably conservative dollar evaluation of one acre of farm land per year. Consideration was given to the percentage of reclaimed lands which would be potentially suitable for agricultural purposes in each of the four sub-basins mentioned above. Land resource soil maps, agronomists (48), and agricultural experts (60) with strip mine knowledge were consulted with regard to the percent of reclaimed strip mines which could be utilized for agricultural purposes. A value of 2 to 3 percent was derived for the Broad Top and Anthracite areas and a value of 5 to 7 percent was decided upon for the West Branch Main Bituminous and North-Central Fields, as well as for the Tioga River Basin. Most experts (60) believed these percentage values were realistic and could, in fact,be increased if more money was spent on regrading and soil treatment (48). For benefit purposes, a minimum percentage value of two will be utilized for the Broad Top and Anthracite Fields and five percent will be applied to the remaining coal fields. An average annual gross crop value of $100 per acre will be used for the four sub-basins.

In order to avoid an incorrect estimation of the value of one acre of

reclaimed land, forest products and agricultural products will not overlap. However, small and big game benefits will overlap because farming areas are an excellent source of game food, and provide some of the best small game hunting found.

Irrigation needs in or adjacent to the Basin's coal measures are relatively small compared to other more fertile and highly productive farm areas. Irrigation is seldom used on many farms except for smaller high dollar yield per acre truck farms which need and can justify the expense of irrigation equipment (48). Apart from the relatively small need for irrigation, little has been determined with regard to the detrimental affects AMD may have on many crops planted in various types of soil. Agronomists at the Pennsylvania State University are actively seeking grants for such studies and do not feel that any conclusive information presently exists.

Using waters polluted by AMD for watering stock has more definite detrimental effects. Cows subjected to AMD, as a primary source of stock water, do not provide milk of suitable quality to market (47). Dairy farming in coal mined areas is limited and insufficient data exists from which benefits could be determined.

STREAM SEDIMENT

Sediment in streams is often tolerated for long periods of time in many areas until hardships or damages arise. Restrictions in stream channels filled with sediment often cause flooding during high flows. Many areas in the Basin, which were severely affected by flooding during tropical storm Agnes, could have been spared some of this damage in the absence of excessive deposits of sediment in stream beds. Sediment also reduces reservoir capacities, and seriously affects aquatic life. In the Chesapeake Bay sediment interferes with navigation (78) which necessitates dredging by the Corps of Engineers. Sediment also affects aquatic life in the Bay.

Other than major problem areas it is difficult to ascertain all other costs incurred by damages caused by sediment or the cost of its removal. According to the best information available (74, 42) an annual average of 0.85 tons of sediment per acre, above the normal, is transported from strip mines in the Susquehanna River Basin. The U. S. Soil Conservation Service can justify expenditures of $1.00 per ton of sediment removed (74). In some special cases expenditures from $2.00 to $4.00 per ton can justifiably be made in the Basin. For benefit purposes in the report a conservative estimate of $1.00 per ton will be utilized. Hence, for each acre of land restored a benefit of $0.85 per

acre per year will be applied. A value of $1.00 per ton was also chosen because strip mines are not the only source of intolerable amounts of sediment.

TIMBER SALES

The current value of one acre of timber was derived from information provided by the Chief of the Division of State Forest Management for the State of Pennsylvania (58) and sawmill owners operating in the State. All persons agreed that a one-acre stand of timber, which would yield 10,000 board feet, would accumulate a value of $300 to $500 every eighty years with proper management. The average annual value of one acre of such timber would be $5. For benefit estimates an average value of $5 will be applied to one acre of reclaimed land annually. Accumulating timber benefits will be made for a thirty-year period since strip mines undergo some natural revegetation within this period.

RECLAIMED LAND VALUES AND COUNTY TAXES

The value of land in terms of hunting, agriculture, timber, and other uses has been previously discussed. The market value of reclaimed land is ultimately that price which the buyer is willing to pay. According to real estate brokers (49) located in the heart of the coal fields, those few lands for sale with aesthetically appealing or natural surroundings are very much in demand. This is reflected by sale values and the length of time these properties remain on the market. Rough mountain land near or in areas which have been affected by mining operations, having no sewage, water or other utility services often sell for $200 to $300 per acre or less. Land within the same area with a natural mountain setting, sought primarily for cabin sites, often sells for $600 to $700 per acre. These value increases are related to, and correlate surprisingly well, with the annual dollar value placed on aesthetics per acre of fully reclaimed land. Some restored lands can have greater recreational potentials developed with careful planning. This further increases the average recreational dollar values established in the preceding sections. Many state and federal agencies as well as university research groups are actively seeking ways to increase the utility of restored lands for varying forms of potential use.

In relatively high population density areas, which are currently being developed, restored lands are utilized for rural expansion, industrial parks, and public utilities. It would be difficult to evaluate each area in the Basin due to the complex involvement of various economic pressures which can alter land values, use, and their demand. Further problems in the appraisal of restored land values arise in the form of a possible duplication of benefits already derived for land use and aesthetics. It is the opinion of the authors that these values may be economically inseparable.

The benefit dollar value ascribed in this section is the increased market value or sales price realized by the owner at time of sale. This will attempt to reflect the minimum increased market value restored lands will eventually achieve, and is therefore pro-rated at $5 per year per acre for 30 years. It is assumed that sufficient restoration of adjacent stripped lands would be completed to insure aesthetically appealing surroundings for the acres of land being evaluated.

An estimation of increased taxes is also difficult to evaluate. Numerous attorneys, land owners (49), chief county assessors (43) and other persons contacted agree that true market values and market values used for assessment purposes are often far apart. Many counties are in need of updating their assessment values and some are currently

undergoing new evaluations.

For the purposes of establishing benefit tax dollar values for the Basin, conservative land market values, (percentages of assessed market values, and applied millage rates) approximating those of Clearfield County will be utilized. Using an increased market value of from $250 to $400 per acre, an assessment of 40 percent, and a combined school and county millage rate of 67.5, increased taxes are $4 per acre.

STRUCTURAL DAMAGES

The Susquehanna River Basin's economic progress is extremely dependent upon a plentiful and readily available supply of water, with a quality suitable to meet the public's everyday needs and increasing industrial demands. Nationwide industrial water needs, also reflected by Basin needs, are greatest for the production of electrical power (5, 38). This has recently doubled in demand nearly every ten years. This industry requires 70 percent of all water currently withdrawn for industrial use. Iron and steel production, chemical and allied products, paper products, and petroleum refining, combined, use another 20 percent. The remaining 10 percent is used for production of other diversified products (38). The paper required to produce one copy of this report required about 180 gallons of industrial processing water. Industries' greatest single use of water is for cooling in the production of electrical power (5). Most industries design their production facilities to cut cost incurred in water use, including any treatment. Water is often recirculated or used less. For example, old steel mills used as much as 110,000 gallons of water (38) to produce a ton of steel. Modern and more efficient plants only use 1,300 gallons per ton of steel (38). Most water withdrawn for industrial use is returned to waterways and only 6 percent is actually lost or incorporated in the product.

Industrial water use is increasing substantially. Since the turn of this century, industrial water use, per capita, has increased six times (38). Although our streams carry a more than adequate volume supply of water, even for future needs, some areas may not have enough water of suitable quality. Industry obtains 90 percent of its water from surface streams, which are more prone to pollution than other sources. The remaining ten percent comes from ground water and public supply sources. Many factors determine the source each industry draws upon: quality, quantity, transport distances, dependability of supply, and other plant oriented considerations.

Within the Susquehanna River Basin, as elsewhere, a dependable source of quality water is always considered in initially planning and locating new industry. The general direction of the Basin's economy will demand more optimum and full use of its natural land and water resources. With continuing decreases in anthracite coal production, new forms of diversified industry are required to take up the slack and strengthen the economy. It would be difficult to estimate to what extent and exactly where future water demands will increase within the Basin.

Needs for good quality water go beyond avoiding extra expense by industry to minimize plant facility damages. Damage occurs to dams,

bridges, conveyance systems and other structures which cannot tolerate acid waters unless costly corrective measures are taken.

Estimated costs of damages, water treatment, and materials which tolerate the corrosive attack of AMD are difficult to fully determine. A large number of municipalities, industries, and government agencies with varying types of AMD problems do not always make a retrievable or separate record of these extra costs. Cost estimates in this section of the report are based on information obtained from the Pennsylvania Department of Transportation (62) and the Appalachian Regional Commission's evaluation (5) of AMD impact on industry in the West Branch Susquehanna River sub-basin and the Anthracite Region.

Extra costs to industry, although a substantial sum of money, are usually insignificant relative to total production costs. It was determined that, on the average, only 2 percent of the sales cost is associated with water use, and that only 3 percent of that cost is incurred in handling polluted water(5). Electrical generating plants, on the average, have the highest additional costs due to AMD, at 0.5 percent of annual production costs. It was further determined that 43 percent of the maximum annual savings to industry would result from a 30 percent reduction in AMD (5). An additional 30 percent, for a total 60 percent reduction, would result in an added 37 percent savings, for a total of 80 percent in annual savings.

Maximum savings would occur with a 90 percent reduction in AMD. All reduction percents are for preventive abatement measures. Reductions by treatment will not be considered because lime neutralization reduces acidity, but keeps total dissolved solids at a high level. This water is of no benefit to users of boiler and process water.

For the purposes of establishing benefits in this report, a 90 percent reduction in AMD at-source by preventive methods will not be considered. This is because of the limited number of areas where an effectiveness of this magnitude could be achieved without using lime treatment. The following list summarizes benefits or savings to the various major industries in the Anthracite Region and West Branch sub-basin. These savings are achieved with a 60 percent reduction in AMD. Dollar values are adjusted by an ENR materials cost index of 787 for June 1973. A materials cost index is used, because materials used to treat or tolerate water polluted by AMD are the greatest type of continuing costs to industry.

ANNUAL SAVINGS WHICH WOULD ACCRUE TO MAJOR INDUSTRIES FROM REDUCTIONS OF 60% IN CURRENT AMD

costs in dollars

Area	Food	Textiles	Paper	Chemicals	Glass	Metals	Electrical		Total
I	4080	2040	410	1090	-	140	8160	=	15,920
II	4080	4080	-	-	-	-	8160	=	16,320
Total	8160	6120	410	1090	-	140	16,320		32,240

Area I - Anthracite Region (Main and North Branch Susquehanna River Basin)
Area II - Bituminous Region (West Branch Susquehanna River Basin)

Total annual savings in the Anthracite Region and West Branch sub-basin to these industrial users of AMD polluted waters alone are $15,920 and $16,320 respectively. For an accumulative period of thirty years, savings (based on June 1973 dollars) are $477,600 and $489,600 respectively. These projected savings are based on current industrial usage and do not include any accelerated usage. Projecting estimates of annual savings developed above by projected sub-basin increases in water use alone would over-estimate benefits or savings for several reasons. Volume of water used is not proportional to costs incurred by industry for handling AMD polluted water, and future technological developments are providing new materials and techniques for industry which reduce cost of handling AMD polluted waters. For example, electric generating plants presently under construction average an additional

$203,000 (5) due to AMD, and future plants constructed about 1990 (about halfway through the thirty-year period) will cost only an additional $164,000 (5), based on June 1973 dollars. Although costs to industries would be reduced due to new technological innovations, increased costs to industry, in general, from greater production and new industries in the sub-basins should have a compensating effect. Projected industrial water needs on a local basis show some fluctuations, however, on a more comprehensive scale (sub-basin trends) industrial water needs will increase sufficiently to create a cost balancing effect.

For the purposes of establishing and assigning benefits within sub-basins the projection of present dollar savings will be used. Over or underestimating projected benefits should be avoided by using current values for the reasons mentioned above. Benefit dollar values are assigned according to the volume of AMD reduction achieved and the anticipated quality of stream or river water.

In addition to the above-mentioned costs to industry, information (6 obtained from the Pennsylvania Department of Transportation indicates that relatively substantial costs for special materials which tolerate AMD are incurred periodically. These costs are usually less than one percent of the total construction cost. Since 1970, eight bridges were constructed in the West Branch sub-basin which required vitrified clay liner plates at a cost of $25,000 for all eight bridges. One recent project required

a cost increase of $30,000 for special treatment of pipes designed to tolerate AMD. Other small projects have had added cost due to AMD, but were not recorded. Based on these additional costs, benefits will be assigned within the sub-basins according to reduction in AMD and its associated corrosive effects. Reaches of a stream which normally have values of pH above 5.2 will not be assigned benefits due to lack of corrosion and where other effects of AMD (scaling) are not a problem.

COAL MINE DRAINAGE ABATEMENT MEASURES

PREVENTIVE MEASURES

Surface Restoration

Surface reclamation techniques are applied for the following reasons. The primary purpose is to limit the formation of AMD by preventing simultaneous contact of one or more of its main components: air, water, and iron sulfide minerals. The secondary purpose of surface reclamation is restoring utility and value to the land. In some cases, complete restoration of the land surface to its approximate natural condition is not required if abating acid mine drainage is the only objective. Complete surface restoration may not always be economically feasible, especially in the Anthracite Region. Surface reclamation reduces the formation of acid mine drainage by promoting: (1) rapid runoff, thereby decreasing infiltration; (2) vegetative consumption (transpiration); (3) near surface moisture retention with eventual evaporation; and (4) reducing free air oxygen contact with acid-forming materials. Decreasing the contact time of water with acid-forming materials should be considered when a large area will not be fully reclaimed. Preventive abatement measures are usually the first to be recommended and provide a wide range of benefits. Their initial con-

struction cost is usually high, but annual maintenance expense is not always required.

Unit costs for the reclamation methods described below were primarily derived from a study (3) of projects conducted in the bituminous coal fields of Pennsylvania and West Virginia.

These methods and costs are directly applicable to the Susquehanna River Basin bituminous coal beds, which have similar geology and a comparable mining history. However, these methods and their associated costs were not always utilized in deriving abatement cost estimates for the Anthracite Region. Both the geology and consequent mining techniques differ from the bituminous fields, except for the Broad Top Coal Fields, which are deeply folded. Deep mining in the nearly vertical seams of anthracite coal creates a special problem for restoration. Extensive removal of the coal opens large void spaces, which are partially filled when the remaining unmined coal, or barrier from the mine workings to crop, falls into the mine. These "crop falls" permit extensive water infiltration and often fall again when filled. Sufficient fill material is usually absent, costly to obtain, and difficult to transport to the site. The thickness, number of seams, and quality of the anthracite coal causes it to be stripped as deep as 900 feet. Strip pits of this size are costly to restore. These conditions, among others, were given

appropriate consideration when cost estimates of abatement were being derived. Experience has shown that application of preventive measures, to the fullest extent economically feasible, and resampling for possible followup treatment (neutralization) is usually the least costly approach taken in abating acid mine drainage (AMD). Listed below are those techniques which have seen actual field application and are of predictable cost and effectiveness. All costs in this section, unless otherwise stated, reflect Engineering News-Record, December 1972 construction cost index updating.

Backfilling and Regrading

Many variables determine the eventual cost of backfilling and regrading, these include: topography, type of strip mining, seam thickness, orientation of seam, total mining history in area, amount and spread of acid coal refuse, acidity and volume of spoil, accessibility to area, availability of on-site materials, and the season of the year the work is done. Analysis (3) of all methods of backfilling and regrading indicate an average cost of $860 per acre. Contour type backfilling averages $950 per acre. Terrace-type reclamation, including pasture, reverse slope, and swallowtail methods, is about 43 percent lower in cost per acre than contour-type. Contour-terrace methods combined average $1,250 per acre. These costs do not include costs of revegetation.

Administration, design, construction inspection, and post-reclamation costs, and water diversion, are not included in the above costs per acre. Access road construction, plus any clearing and grubbing, is included in the $1,250 per acre value. Although little information exists to substantiate access road cost alone, it appears that $2.50 to $3.00 a linear foot, including clearing and grubbing, is a realistic value (3). Additional road work, including culverts and other drainage structures, would increase the cost. Stream diversion costs, based on three "Operation Scarlift" reports, range from $12 to $27 per linear foot. Costs vary due to depth of cut, cubic yards excavated, and the materials used. Planting costs are not included in the above mentioned linear foot prices.

Refuse Bank Contouring and Grading

The costs involved with refuse bank contouring and grading listed here do not include costs of revegetation, sealants, clearing and grubbing, or access road construction. Analysis of construction cost data indicates an average cost of $1,000 per acre, on an average $.75 per cubic yard. Soil cover for graded refuse banks is estimated to average $2,500 per acre or $3.00 per cubic yard. Fringe benefits derived from the removal of refuse material are: secondary coal recovery, base material for roadways, anti-skid use, and the production of brick. These benefits,

if realized, could substantially reduce the $1,000 per acre cost, without soil, and increase the benefit/cost ratios within the Basin.

Clearing and Grubbing

Analysis of cost data indicates that a wide range of cost values exist, from $33 to $700 per acre, with a mean value of $200 per acre (3). Factors which vary the cost are: amount of solid waste present and acreage, topography, size-growth density, and fringe benefits such as cutting pulpwood and chipping for mulch, thus avoiding the cost of burying and burning.

Revegetation

The success of surface restoration ultimately depends upon the establishment of a healthy vegetative cover. Vegetation's main purpose is the retention and consumption of moisture, which otherwise could infiltrate and increase acid mine drainage production. A vegetative cover also blocks the flow of oxygen. A good vegetative cover prevents erosion and siltation, thus, at the same time, preserving its ability to serve its main function.

In 1972 new Pennsylvania State reclamation laws required the replacement of topsoil, after surface mining operations were completed.

This increased the number and varieties of plant types which could be successfully seeded.

Prior to 1972 the variety and number of plants which could be used, as well as the number of basic considerations given to planting, were few.

Although extensive revegetation of reclaimed lands has taken place only recently, a vast amount of information to aid successful planting does exist. The primary goal of this report does not permit mention of all considerations, therefore, only several will be given. All considerations are directly or indirectly related to: soil or slope stability, proper long term pH response, proper nutrients, soil moisture and temperature, and natural plant succession. Specific considerations include the application of fly ash in order to increase the buffering capacity of spoils (fly ash properties vary), realization of maximum pH's by prolonged liming of spoil, limiting the velocity of water draining from an area, soil testing for lime and nutrient requirements after grading, determining drainage and moisture retention characteristics of soil or porosity, finding the organic and toxic salt content, designing the seeding mixture and mulching, utilizing to the best advantage existing climate, and consideration of wildlife needs. With proper game food planting in areas which possess the requisite potential, it is possible, with the aid of Pennsylvania Game Commission

recommendations, to potentially increase the number of big and small game recreational days. It is also possible to greatly increase the productivity of the land or its real estate value by planting timber crops for a number of uses, or returning the land to dairy, livestock, and crop usage (48).

Maximizing the above mentioned utility of the land should greatly increase the benefit/cost ratios within the Basin. With proper planning it has been demonstrated, in some cases, that it is possible to increase the utility of the land beyond its former (pre-mined) value.

Based upon a wide variety of soil treatment and seeding projects, analysis of past cost data indicate an average of $270 per acre. However, it is probable that with application of the latest techniques, future planting costs will range between $350 and $400 per acre (3). A number of State, Federal, and Public agencies offer guidelines for revegetating reclaimed strip mines (60).

The effectiveness of surface reclamation work in abating coal mine drainage pollutants depends upon a great number of individual factors. These factors are related in that they are concerned with the volume and simultaneous contact time of the three mine drainage constituents, air (free and dissolved oxygen), water, and iron disulfide minerals, along with temperature and any other parameters which are attributed to

promoting acid mine drainage production. A 20 to 70 percent reduction (3) of acid mine drainage can be achieved, depending upon how successful infiltration volumes can be reduced, and the simultaneous exclusion of any one of the three acid mine drainage contributors could be achieved. In most cases, on the average, abatement projects utilizing preventive measures to the greatest extent, realized a 25 percent effectiveness value for areas containing seams of relatively high amounts of sulfide minerals. Percentages as high as 70 can be obtained if the underlying seams which receive this infiltration have not been deep mined extensively or if the coals contain moderate amounts of sulfide minerals.

A value of 100 percent is occasionally reported with regard to placing impermeable seals on the ground. This may be possible and even practical for small areas, but has not seen much use on a large scale. The placing of large seals, depending on the procedures, may even detract from the utility of the land. In this report, unless otherwise known from reliable studies, a value of 25 to 70 percent effectiveness for preventive measures will be used.

The cost estimates were based on adequate compensation to construction companies to reclaim old and abandoned strip mines. Many acres of old strip mines are and will be restripped depending upon the coal market, state, and federal regulations. It would be extremely difficult to

estimate the percentage of the old strippings that will ultimately be re-stripped in the future. Pennsylvania's strip mine operators, according to the DER (24), are currently restoring over 15 square miles of old stripping annually. Current cost to strip mine operators, for reclamation work as required by current law, is estimated to cost $300 per acre, with some costs running near $500 per acre (3), including revegetation. With proper planning old strippings adjacent to those being reworked could be reclaimed along with the active sites, at a cost savings to the taxpayer. This would effectively decrease reclamation costs and have the effect of increasing the benefit/cost ratios within the Basin.

Mine Sealing

Abandoned deep mines are the greatest single sources of untreated acid mine drainage. Lime treatment methods are generally utilized at active operations to bring the discharge within water quality standards prescribed by law. The majority of the discharges are emanating from deep mines which have ceased to operate for many years. The idea of sealing coal mines for the purpose of abating acid mine drainage has appeared in the literature as far back as the early 1920's. The first type of seals which were employed to any extent were air seals. These were designed to preclude the passage of air into a mine without, however, preventing its discharging. Although these seals have been

reported to work in some cases, for a period of time, they are no longer considered an effective means of abating acid mine drainage by most experts in the field.

Another type of seal which is sometimes utilized is a dry seal. This seal is used to prevent the free passage of air and water into the mine and, to some extent, could be considered a water diversion technique. These seals are used where there is only a slight possibility of any hydraulic head forming.

Recent advancements in the field of mine sealing have developed around the hydraulic mine seal. Hydraulic seals are placed at a gravity discharge point and preclude further passage of water from the mine. Consequently, the mine pool rises, inundating the mine's workings, forcing out all air and rejecting some recharge to the pool and consequently reducing the formation of acid mine drainage. The hydraulic head which develops should be controlled by overflow mechanisms in the event that it is neither practical or possible to construct a seal which can withstand the total head which could develop in the mine.

Since the majority of effective mine seals being constructed presently are of the hydraulic type, no further mention of dry, air, or other type seals will be made. The success of a hydraulic seal depends upon much careful planning, including extensive field surveys. All entryways,

boreholes, stripped crop barriers, and natural passages must be sealed.

Although most of these larger, more obvious, air and water passageways may be found and sealed, dissolved oxygen (10-14 ppm) in water perculating downward and eventually passing through mine workings can form some acid mine drainage. In some cases natural alkalinity surrounding the mine workings may neutralize this acid.

The highest percent of success in placing seals has come from constructing them from within the mine. Otherwise, seals of generally less effectiveness must have bulkhead and grouting materials placed via boreholes. Inspection work is also accomplished with borehole cameras and other exploratory devices. A brief discussion of the grouted double bulkhead seal will be given due to its extensive use, effectiveness, and known cost. Other methods are presently in the experimental stage and may see future application.

Under "Operation Scarlift" Project SL-105-3, sixty-nine grouted double bulkhead seals were placed in Moraine State Park, Butler County, Pennsylvania. Each seal was curtain grouted a minimum of 50 feet horizontally on both sides of the sealed entry. The actual average cost per seal, including curtain grouting, was $19,600 (3). Individual seal costs ranged from $8,300 to $58,000. Since all 69 seals were placed by the inaccessible portal method, accounting of materials and costs was difficult

to estimate. Subsurface conditions were difficult to ascertian without extensive and costly subsurface testing. Analysis of cost data indicated that about 60 percent of the total cost went toward curtain grouting, which averaged $80 per linear foot. Subsequent reduction in pounds of acid was reported to be 68 percent. One other extensive mine sealing program involving 24 seals, undertaken in the Slippery Rock Creek area, is averaging $18,330 per seal including curtain grouting. Both mine sealing programs involving 93 seals averaged $19,300. Hydraulic seals for accessible mines of the reinforced concrete type range from $15,000 to $20,000 each (3), including 100 linear feet of curtain grouting, 50 feet horizontally on both sides of the seal. Other hydraulic sealing methods could be mentioned, but their effectiveness and cost is not well substantiated.

TREATMENT MEASURES

Applications and Considerations

Treatment as an abatement measure should only be applied after preventive measures, with minimal annual maintenance cost, have been applied to the fullest extent economically possible. Preventive measures obtained an average reduction in acidity (effectiveness) of about 25 to 70

percent for full surface restoration, and 68 percent for hydraulic mine sealing. Treatment methods offer 100 percent effectiveness possibilities, but also the greatest long-term cost. A large number of watershed studies have indicated that except for neutralization, other treatment methods can seldom be applied due to much higher cost. Deep mines with extensive mine workings and large discharges usually have a high hydrostatic head potential, an uncertain recorded history, numerous entryways, and weak, or sometimes stripped crop barriers, making them difficult to seal.

Mine drainage chemistry is quite complex, and many of the details must still be worked out. There are, however, some common denominators. The four major types of mine drainage with increasing pH are: (1) a very high acid, high ferrous iron, high sulfate type; (2) a high acid, high ferric iron, high sulfate type; (3) high sulfate; and (4) a high ferrous iron, high sulfate type. Neutralization techniques are developed around the mixing of a chemically basic substance with the acid mine drainage to neutralize the acid, and precipitate the salts, which are only slightly soluble at acceptable pH levels. Although there exists over a dozen common neutralizing agents, only lime, limestone, and a combination of both have been extensively used.

The type, size, and location of mine drainage treatment plants depends upon many factors. If more than one outfall exists, relatively close to one another, it may be cheaper to locate one plant for cumulative treatment. A water sampling program for the chemical characteristics of the discharge, along with flow behavior must be conducted. Type and availability of the neutralizing agent together with the reaction time and sludge characteristics must also be taken into account. The resultant hardness or possible increased solids (dissolved or undissolved) in the effluent should not exceed limits set by law or present more of a problem than that being solved. Natural alkalinity in the region should be used to abate AMD if possible. After a period of about 10 to 15 years cumulative operating costs can equal or begin to exceed initial costs due to annual labor and material expenditures. A discussion of some of the specific considerations regarding the advantages, disadvantages, and costs of lime, limestone and a combination of lime-limestone treatment methods are given below.

Limestone Neutralization

The use of limestone reduces the size and space requirements for settling basins due to the reduced volume of sludge, as compared with pure lime treatment. Other advantages are the lower cost of the neutralizing agent and its safer handling characteristics. Limestone, however, does not

oxidize ferrous iron rapidly. This requires other costly construction to overcome this shortcoming. When ferrous iron concentrations approach 5,000 ppm (3), increased sludge volumes and scaling void the use of limestone as well as lime; therefore, more efficient oxidizing processes must be incorporated with treatment to minimize these problems. Limestone used as a neutralizing agent should contain a high percent of calcium carbonate and have minimal amounts of magnesium precluding the use of magnesium rich dolomites. All costs given in Table 3 assume that excessive costs are incurred due to difficulties in locating the treatment plant facilities. Such difficulties would be the suitable placement of a plant with regard to topography, low water table, depth of bedrock, and type of soil. These costs include a 25 percent safety factor for treatment in excess of the anticipated maximum acid and ferrous iron loads. Holding ponds are designed to hold three days of maximum anticipated daily flow in the event of a plant breakdown. The costs given in Table 3 were estimates made December 1969. The ENR construction cost index was 1305. The costs in the table cover a small range of acid and ferrous iron concentrations with flows from 0.1 to 6.0 mg/d. More data (3) can be obtained from the Appalachian Regional Commission's report titled "Analysis of Pollution Control Costs."

TABLE 4
LIMESTONE TREATMENT PLANT COST ESTIMATES

Plant Capacities	Acid / Ferrous Iron	Concentrations (ppm) 500 / 50	1000 / 100
0.1 mg/d	total capital cost	$ 29,400	$ 31,900
	annual operating costs	$ 8,800	$ 9,300
	cost/1000 gal.	24.1¢	25.5¢
0.3 mg/d	total capital cost	$ 38,100	$ 48,800
	annual operating costs	$ 10,500	$ 12,500
	cost/1000 gal.	9.6¢	11.4¢
0.5 mg/d	total capital cost	$ 53,800	$ 76,900
	annual operating costs	13,500	$ 18,500
	cost/1000 gal.	7.4¢	10.1¢
1.5 mg/d	total capital cost	$107,100	$170,300
	annual operating costs	$ 24,300	$ 38,000
	cost/1000 gal.	4.4¢	6.9¢
2.0 mg/d	total capital cost	$115,600	$190,000
	annual operating costs	$ 21,500	$ 43,400
	cost/1000 gal.	2.9¢	5.9¢
6.0 mg/d	total capital cost	$263,800	$458,800
	annual operating costs	$ 44,200	$101,800
	cost/1000 gal.	2.0¢	4.6¢

Cost after Mihok 1970 ENR CI 1305 reported in the ARC's "Analysis of Pollution Control Costs."

Lime-Limestone Neutralization

The combination method, using lime and limestone as the neutralizing agents, exploits their individual primary advantages and avoids some of the disadvantages of each. For example, limestone cannot rapidly oxidize ferrous iron above a pH of 7. At lower pH's limestone is more economically effective. Full utilization of lime, especially in the lower pH ranges, creates a voluminous sludge problem which can be alleviated by using limestone or other more costly techniques. The EPA has studied treatment of deep mine discharges with a pH of 2.8, acidity of 430 ppm, and a total iron content of 92 ppm, using the combination method. This method, relative to the use of a single agent, reduced material costs 25 percent for pH to 6.5, and decreased sludge volumes up to one third of that accumulated for comparable lime neutralization. Process economics investigations by Wilmoth, et. al. showed that as the ratio of lime over limestone raw material cost exceeds 1.8:1 additional cost reductions, using the combination method, are achieved and the reverse is true as the ratio becomes less. Although the initial costs of a combination treatment plant are greater, the lower cost of materials should produce lower

long-term cost. Cost data for increased efficiency lime-limestone treatment for several plant capacities can be found in the Machael Baker, Jr., Inc. 1973 ARC report concerning analysis of pollution control costs.

Hydrated Lime

The majority of AMD treatment plants in the Susquehanna River Basin use lime as a neutralizing agent (3). It is expected that future plants may use the lime-limestone combination method. Many of the plants now in use were the first to be constructed, and their planning lacked the information that was gained through their operation. Technological advancements always evolve in this manner and should provide for more efficient operations as time progresses.

The hydrated lime treatment process involves neutralization, aeration (oxidation of ferrous to ferric iron), clarification or thickening, sludge dewatering, and sludge disposal. The advantages of using lime in addition to those mentioned in preceeding sections are its availability, reduction of dissolved salts, and its mechanical manipulation.

Specific considerations given to engineering costs are as follows. The quality of the discharge is slightly more important than quantity in determining treatment cost. Topography, geology and availability of land must be considered in determining the nature of the treatment facilities built. These factors affect size and number of settling lagoons, mixing and aeration facilities, and sludge handling and disposal.

Electrical Oxidation--Limestone

The EPA has investigated techniques which electrically oxidize ferrous iron to its ferric state prior to its neutralization by limestone. Limestone can neutralize the resulting mine drainage more economically with its low ferrous iron concentrations. The electro-chemical process frees electrons, which combine with hydrogen ions to form hydrogen gas. This can be sold to offset treatment cost. In addition to the sale of hydrogen gas, treatment plant cost reductions are achieved through the elimination of aeration equipment, the use of low cost limestone, and lower costs for sludge disposal. The costs of electrical oxidation--limestone treatment are dependent on chemical characteristics and flow of the mine drainage, costs of materials, and the income through sale of the hydrogen gas by-product. Little data is available which supports the cost of full scale operations. This method, along with others being developed, is an attempt to apply a combination of highly effective techniques which together offer the best overall economic approach.

Biochemical Oxidation--Limestone

Acidophilic iron bacteria oxidize ferrous iron to its ferric state, in addition to utilizing CO_2 for a source of carbon for growth and production.

Investigations using these bacteria in treating AMD has been conducted in Great Britain. Cost information derived from full scale plant operations is not available.

Ozone Oxidation--Limestone

The Brookhaven National Laboratory studied the feasibility of ozone oxidation with neutralization by limestone. Ozone, which is reprocessed, is used to oxidize ferrous to ferric iron. Different methods of ozone production were studied. No conclusions were reached in their study which have been verified by full-scale testing. Therefore, no further information or cost is given here.

Flash Distillation

This method involves the evaporation and condensation of AMD with the simultaneous production of desirable potable water and less desirable caustic solids which present disposal problems. The Pennsylvania DER evaluated this means of treating AMD and found it not acceptable for a number of reasons, which included high operating cost and ground water safety problems.

Ion Exchange

This method depends upon a reaction of metal salts and hydroxides in AMD with anionic and cationic resins. This method is currently being evaluated by the Pennsylvania DER (50) and little information from large scale plants exists. Operating costs may be too high to allow any extensive use of this process.

Reverse Osmosis

Osmosis is well known on a small scale and involves the use of a semi-permeable membrane which allows the solvent to pass through the membrane but not the solute until both solutions have an equal dilution or until the osmotic pressure value is reached. Reverse osmosis is achieved when a pressure is applied to the more concentrated side and the solvent flows to the more dilute side of the membrane. This method is undergoing investigation and has seen little use in abating coal mine drainage. Only those treatment techniques which have been tested on a full scale basis and are of predictable cost will be considered for abatement estimates within the Basin. Techniques which do not depend primarily on lime or limestone may see only limited use.

SUB-BASIN DISCUSSIONS
BITUMINOUS REGION

WEST BRANCH SUSQUEHANNA RIVER

The West Branch Susquehanna River drains an area of 6,900 square miles in the west central part of the Susquehanna River Basin. The sub-basin lies entirely within Pennsylvania and is bounded on the north by the Genesee and Chemung River Basins, on the south by the Juniata River Basin, on the east by the North Branch Susquehanna River sub-basin and on the west by the Allegheny River Basin.

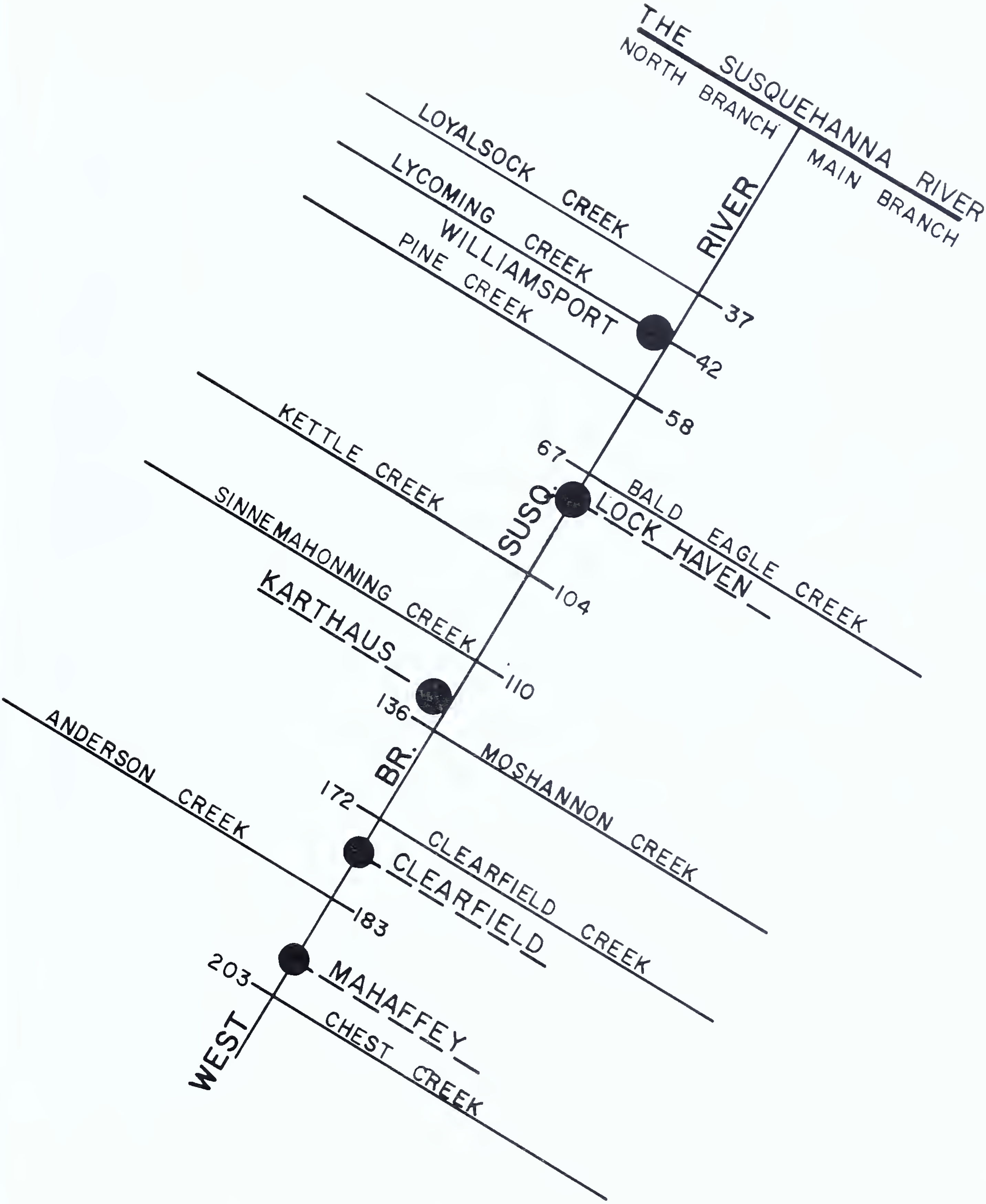
The West Branch Susquehanna River has its source in north-western Cambria County and flows a distance of 240 miles to its confluence with the North Branch Susquehanna River at Northumberland, 123 miles upstream from the Chesapeake Bay(Plate 1). The upper part of the sub-basin lies within the high tablelands of the Appalachian Plateau Province. At Lock Haven, the river breaks through the Allegheny Front, the escarpment which divides the Appalachian Plateau Province from the Valley and Ridge Province, and then flows approximately 70 miles through the Valley and Ridge Province to its confluence with the North Branch Susquehanna River. The area of the sub-basin is approximately equally divided between the Appalachian Plateau and the Valley and Ridge Provinces. In the Appalachian Plateau Province, stream valleys are narrow and flanked by high, steep hills. In the Valley and Ridge Province, valleys are

generally broad and fertile and bounded by rugged, forested mountains. Moderate to steep gradients of streams in the Appalachian Plateau Province provide considerable turbulence and consequently good mixing of waters. The combination of low gradient and a wide, shallow channel configuration combine to produce poor mixing of river waters in the Valley and Ridge Province.

Major tributaries of the West Branch, which are discussed in the following sections, are listed below with their drainage areas, mile points of confluence with the West Branch and shown on figure 3.

Stream Name	Drainage Area (square miles)	Mile Point of Confluence
Chest Creek	132	203
Anderson Creek	110	182
Clearfield Creek	396	172
Moshannon Creek	288	136
Sinnemahoning Creek	1,033	110
Kettle Creek	239	104
North Bald Eagle Creek	782	67
Pine Creek	973	58
Lycoming Creek	276	41
Loyalsock Creek	493	37

Listed below are monthly averages of flow from the West Branch of the Susquehanna Watershed at Williamsport. This Watershed above Williamsport contains all areas of the West Branch which are underlain by coal except for a small region in the Loyalsock Creek area.



MAJOR TRIBUTARIES TO THE
WEST BRANCH SUSQUEHANNA RIVER
SCHEMATIC DIAGRAM OF STREAMS AFFECTED BY
MINE DRAINAGE POLLUTION

FIGURE 3

Month	Average flow cfs	Flow/Sq. Mile of Drainage Area
January	9,733	1.71
February	9,759	1.72
March	21,560	3.79
April	18,470	3.25
May	12,660	2.23
June	6,564	1.15
July	3,701	0.65
August	2,601	0.45
September	2,263	0.40
October	3,691	0.65
November	6,236	1.10
December	7,837	1.37

The West Branch of the Susquehanna River has a yearly average flow of 8,679 cfs (40) from its 5,682 square miles of drainage area above Williamsport or 1.53 cfs per square mile of drainage area. Monthly average flows are below the yearly average the last seven months of the year. During the first six months of the year stream flows average 1.5 times the yearly average and during the last six months are only half of the yearly average. Most water quality sampling and flow measurement data available for the West Branch was collected during lower than average flow periods. This results in an underestimation of yearly average AMD and natural alkalinity loadings. One other hydrologic factor which creates an underestimation flow bias is the fact that higher than average flows occur only 25 to 30 percent of the year. Flow data from most sources underestimated the average flow per square mile and the AMD loadings. Over or underestimations of flow are discussed

in the individual watershed sections and may be determined from the drainage areas presented in the report. Yearly average flows may vary from 1.2 to 1.7 cfs per square mile of drainage area within the sub-basin depending on rainfall, amount of deep mining, and structural controls on ground water movement.

The following data for the West Branch was collected by the DER (50) during a sampling period from 1970 to 1972. The data below is based on 1 to 14 samples per station with a median of 1 and mean of 2 samples per station.

WATER QUALITY DATA AND FLOW
MAINSTREAM WEST BRANCH SUSQUEHANNA RIVER

Station	Flow cfs	pH	Net Alkalinity ppm	Sulfate ppm
Spangler	31	8.2	501	1,995
North Barnesboro	67	6.9	135	1,156
Garmantown	88	7.0	18	907
Cherry Tree	111	7.2	22	885
Stifflertown	108	5.7	-23	636
McGees Mills	185	6.9	21	312
*Bower Station	420	7.1	20	195
Curwensville	2,200	6.4	22	170
Clearfield	265	7.1	26	125
Deer Creek	---	5.2	-24	144
Rolling Stone Creek	---	4.3	-37	182
Karthaus	1,076	4.2	-30	182
Renova	8,384	4.6	-14	106
Lock Haven	---	4.9	-6	67
*Williamsport	6,800	6.8	13	48
Lewisburg	8,600	6.8	15	61

*Denotes USGS Gage Station
-Net alkalinity is equivalent to net acidity

Although acid mine drainage indicators may be found the full length of the West Branch, the above data shows that the reach between Clearfield and Lock Haven is almost always acid. Portions of the remaining upstream and downstream alkaline reaches, can turn acid at times. The upstream reach of the West Branch is affected mostly by a few acid tributaries and slugging from seepage from coal refuse piles which, during high flows, can produce up to a 100,000 ppd acid load (50). Downstream from Renovo, the West Branch is occasionally affected by higher than average acid production in the Clearfield, Moshannon, and the Bennett Branch Sinnemahoning Creek Watersheds along with acid contributed by small watersheds in this reach of the West Branch.

The descriptions and conclusions for the following watershed sections were based on interpretations of available data which varied in amount depending on the watershed. In some areas the DER's AMD Operation Scarlift data, which gives a good account of AMD activities, was used as a guideline for adjacent watersheds. A brief account of the individual Scarlift reports is presented where available.

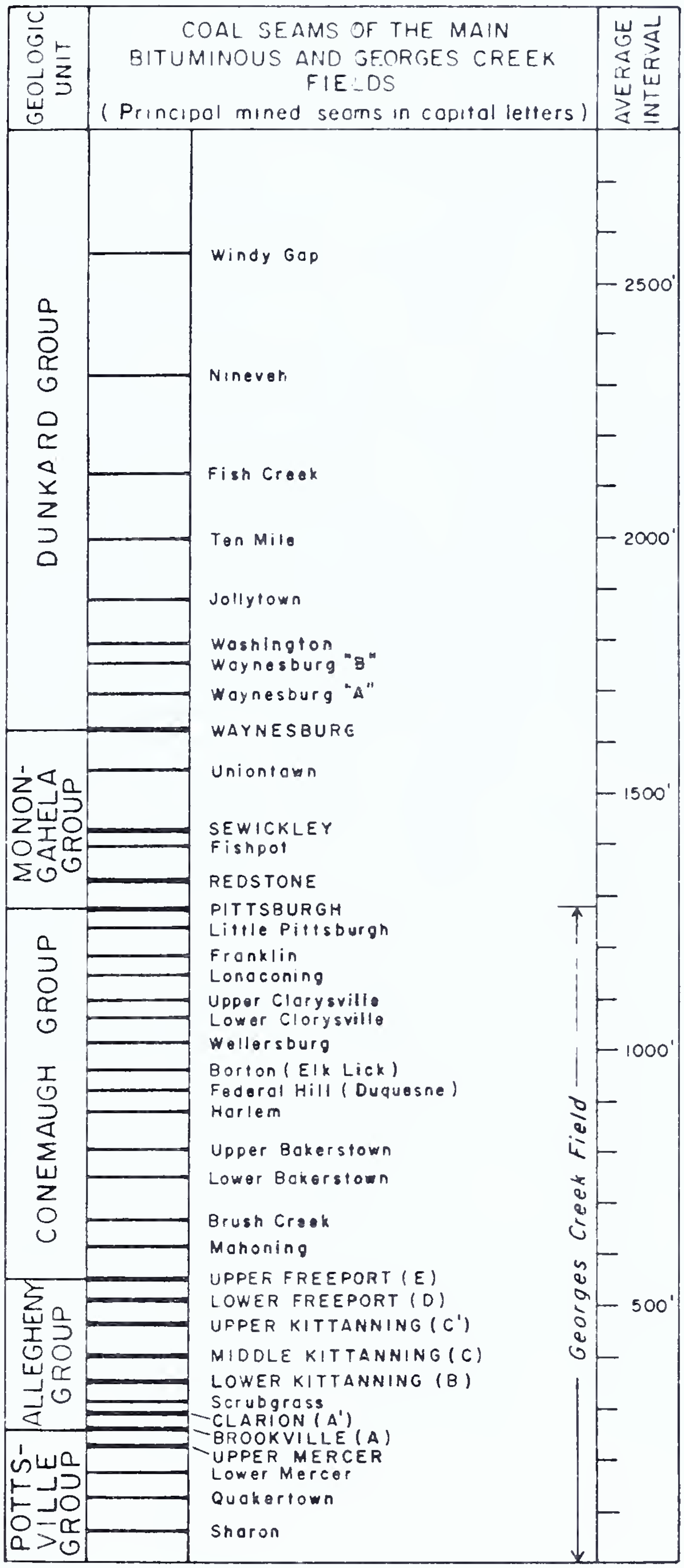
Rock units which outcrop in the area were deposited during the Pennsylvanian and underlying (older) Mississippian Periods within the

Paleozoic Era. In descending order from youngest to oldest, the specific rock units are the Conemaugh, Allegheny, and Pottsville Group rocks underlain by the non-coal bearing Mauch Chunk Shale, Pocono, Oswego, and Catskill Formations. Formations containing coal are usually gently downfolded into synclinal basins, which spared them from erosion and removed the coal deposits from the adjacent anticlines. Several synclines and anticlines are found in this bituminous region and are discussed in the individual watershed sections with regard to their association with ground water movement and AMD production. A large number of wrench faults are found in the West Branch area, being least numerous to the northwest.

The Allegheny Group rocks contain the most frequently mined coal seams and clay deposits in the West Branch area. The Clarion Formation contains up to three separate seams with associated clays. The Clarion coal seams are commonly referred to as the "A" coals (figure 4) with up to nine feet of total coal. The Kittanning coals "B", "C" and "C'" are known as the Lower, Middle and Upper Kittanning seams. The three seams are usually not separated by more than thirty feet of rock. The Lower Kittanning is split into five seams in some localities but usually consists of the main seam and a small rider vein. The Lower Kittanning is the thickest of the Kittanning coals and was frequently deep mined. The Middle and

FIGURE 4

GEOLOGIC SECTION FOR MAIN BITUMINOUS FIELDS



Adapted from 1973 Keystone Coal Industry Manual

Upper Kittanning coals vary in thickness but are usually thinner than the Lower Kittanning. Mining of Kittanning and Clarion coals often results in AMD. The Freeport coal (Lower-"D" and Upper-"E") seams are usually the highest quality coals and have the lowest average content of ash and sulfur. The Lower Freeport coal is also split three ways. A fresh water limestone (77) is deposited between the Freeport coals in some areas varying from two to fifteen feet in thickness. The highest coal mined in the Allegheny Group is the Upper Freeport which ranges from 1.5 to 3 feet in thickness. The Upper Freeport is of approximately the same quality as the "D" coal which is usually thicker and has a lower average ash content.

Coal mining is the most important industry in the West Branch area. Mining activities began in the early 1800's and expanded greatly up to the Civil War. Although some strip mining began in the early 1900's, large operations did not prevail until after the mid-1940's. In 1918 total bituminous coal production in Pennsylvania reached a peak of 177.2 million tons. Since then, production decreased to a low of 76 million tons by 1938. In response to the war effort, coal production increased to 144 million tons by 1944. After World War II production decreased to 63.1 million tons by 1961. Since 1961, production increased to 81 million tons and has remained relatively stable for the last ten years. In 1970, total production for deep, strip, and auger mining was 55.3, 24.1 and 0.59 million tons respectively

for a total of 80 million tons. Strip mine production alone hit a peak production of 35.9 million tons (11) in 1947 and decreased to 16.9 million tons in 1954. Since then, strip production is holding stable at 21 to 24 million tons per year. Estimates of total coal production for 1971 was placed at 71.2 million tons 11 percent lower than 1970. Clearfield County, which lies entirely within the West Branch area, had a total production of 5.9 million tons in 1970 of which 1.2 million was deep mined. In Clinton County, strip mining accounted for the total production of 0.45 million tons. Total production for the entire West Branch area was about 11 million tons in 1970.

The North-Central Fields contain bituminous and semi-anthracite coal underlying parts of Bradford, Lycoming, Sullivan, and Tioga Counties. The Main Bituminous Field underlies all other counties in the West Branch sub-basin.

Total bituminous coal reserves as of 1970 were estimated at 96.0 million tons (14) for the North-Central Fields and 6,065 million tons for the Main Bituminous Field within the West Branch sub-basin. Recoverable coal reserves are estimated at 24.0 million tons (14) for the North-Central Fields and 1,330 million tons for the Main Bituminous Field underlying the West Branch Watershed.

West Branch - Upstream from Chest Creek

The West Branch flows northwest from Carrolltown (Plate 1) toward the northwest corner of Cambria County. From this point the West Branch flows north to its confluence with South Branch Run near McGees Mills and then flows two miles east to its confluence with Chest Creek north of Mahaffey.

Nearly all of the West Branch upstream from Chest Creek is underlain by Allegheny and overlying Conemaugh Group rocks which contain all seams commonly mined. Extensive mining, both deep and strip, has taken place below Cherry Tree, located near the southwest corner of Clearfield County.

The DER (50) conducted a study of the West Branch upstream from Chest Creek in addition to making a brief survey of water quality on the West Branch as far east as Lewisburg. Portions of those findings are presented below. During the sampling period from September 1970 to September 1971 the West Branch had an average pH of 8.2 at Spangler. Average concentrations of mine drainage indicators were 500 ppm alkalinity, 44 ppm iron, and 2000 ppm sulfate. Alkalinity originates in numerous old "D" seam (figure 4) deep mine working downstream from Spangler. These alkaline flows can normally neutralize up to 6,000 ppd acid or about 10 percent of the acid in this reach of the West Branch. Strong acid discharges from

"B" seam deep mines are more numerous upstream from Spangler and flow directly into the West Branch. These deep mine sources of AMD contribute an average 20,000 ppd acid to the West Branch just upstream from Spangler. This represents about 30 percent of all acidity formed upstream from Spangler and also represents nearly all deep mine drainage upstream from Spangler. Refuse pile drainage also represents a major source of acid in this reach of the West Branch. Large acid-forming refuse piles are found along the West Branch and its tributary streams where coal was loaded at tipples and transported north by the Pennsylvania Railroad. Within the study area about 6 million tons or 5.6 million cubic yards of refuse are contained in twelve refuse piles spread over 192 acres. Total acid loadings emanating from these piles ranges from 36,000 to 100,000 ppd. Under normal stream flow conditions refuse piles account for about 70 percent of the total acid in the study area, the remainder emanates from "B" seam deep mines upstream from Spangler. The location of these refuse piles in some cases will complicate their removal or burial.

The tributaries of the West Branch in this area and their water quality are listed below. This data is based upon the U.S. Army Corps of Engineers (CE) sampling in the summer of 1970 and the DER data collected from that time until the summer of 1971. Corps of Engineers data was collected during a summer low-flow period. The DER's relatively

higher flow data offers an indication of how alkaline and acid concentrations respond to increases or decreases in flow.

Tributary Name	Loading ppd	Alkaline ppm	Acid ppm	Flow cfs
Leslie Run (CE)	362		181	0.37
Hoppel Run (CE)	116	53		0.41
Fox Run (CE)	2,345		131	3.33
Browns Run (CE)	13,830	268		9.57
Browns Run (DER)	8,875	185		8.90
Walnut Run (CE)	5,000	175		5.30
Walnut Run (DER)	5,000	120		7.90
Porter Run (DER)	540	120		0.83
Moss Creek (CE)	2,480	137		3.36
Moss Creek (DER)	2,460	38		12.0
Douglas Run (CE)	536	144		0.69
Douglas Run (DER)	1,900	88		4.00
Emeigh Run (DER)	1,120	31		6.70
Peg Run (DER)	100	31		0.60
Cush Cushion Creek (CE)	270	45		1.10
Cush Cushion Creek (DER)	730	27		5.0
King Run (DER)	45	15		0.56
Boiling Spring (DER)	30	10		0.61
Shryock Run (DER)	220	24		1.7
Beaver Run (DER)	8,450	134		11.7
Beaver Run (CE)	2,800	222		2.32
Sawmill Run (DER)	100	21		0.9
Cush Creek (DER)	1,100	24		8.9
Cush Creek (CE)	1,275	30		7.89
Deer Run (DER)	200	30		1.30
Bear Run (DER)	4,000		36	20.70
Bear Run (CE)	1,500		62	4.4
Whiskey Run (CE)	300	29		1.94
Whiskey Run (DER)	400	22		3.5

The tributaries listed above contribute an average 36,000 ppd alkalinity to the West Branch. The response of the West Branch to these

tributaries and direct discharges of mine drainage is given in the following. North of Spangler and upstream from Porter Run the West Branch's pH and alkalinity have decreased slightly to 6.9 and 187 ppm respectively. At Garmantown above Moss Creek the West Branch had an average pH of 7.0. Between November 1970 and June 1971, pH dropped to 4.1 at which time a concentration of 132 ppm acidity was recorded. Concentrations of alkalinity remained below an average 18 ppm after November 1970. Very high concentrations of sulfate and high pH values recorded during the Fall of 1970 probably indicates the flushing of "D" seam deep mines which are alkaline in nature. This data is difficult to interpret due to the wide range of net alkalinity. Upstream at Cherry Tree water quality remained unchanged except for pH which averaged 5.7. At McGees Mills water quality in the West Branch improved. An average pH of 6.9 was recorded. However, a low pH of 4.4 was recorded on September 15, 1971, and a low of 3.6 was also noticed at Garmantown downstream from Moss Creek. At this time, an unusually low concentration of 12 ppm acid and 13 ppm iron accompanied a low pH value. This would indicate that acid slugging associated with a high flow of 1,070 cfs neutralized an average 36,000 ppd alkalinity and created an acid load of 64,000 ppd. This slug of acid was most likely caused by bony refuse which is deposited along flood plains in the headwaters of the West Branch. The effects of this acid slug were also noticed at Bower Station, where a minimum pH of 5.8 was recorded

and concentrations of iron reached a high of 37 ppm. Information (50) obtained for this report indicates that the proper hydrologic conditions are likely to occur at least once a year that promote acid slugging on the West Branch along its entire length, from headwaters to mouth. However, AMD slugging is not likely to affect the full length of the West Branch at any one time.

Abatement of AMD in this reach of the West Branch will most likely involve the implementation of extensive surface restoration of refuse piles and strip mines overlying acid "B" seam deep mines. Mine sealing will be effective only on a very limited basis if at all. Abatement of AMD and the reduction of acid slugs in this reach of the West Branch will insure suitable water quality on the West Branch upstream from Chest Creek. In addition to this, abatement of AMD will also increase alkaline reserves needed to neutralize AMD downstream from Clearfield Creek. Abatement costs are estimated at $12 million initially.

Chest Creek

Chest Creek flows north from its headwaters near Loretto in Cambria County to its confluence with the West Branch just north of Mahaffey in Clearfield County. The entire watershed is underlain by Allegheny and overlying Conemaugh Group rocks which contain coal bearing formations found in adjacent watersheds (77). Mining activities were quite extensive in the southwestern and eastern middle sections of the watershed.

Water quality information made available by the DER indicates that Chest Creek, with an average flow of 155 cfs, discharges 24,200 ppd alkalinity to the West Branch. Concentrations of AMD indicators are 29 ppm of alkalinity, 2.5 ppm of iron, and 139 ppm of sulfate. Corps of Engineer water quality data collected during the summer of 1970 indicates that Chest Creek, during this time, discharged an average 11,400 ppd alkalinity to the West Branch with an average flow of 64 cfs. Mean concentrations of alkalinity, iron, and sulfate were 33, 2.5, and 200 ppm respectively. EPA data from June 1966 to August 1968 indicated that Chest Creek, with a measured mean flow of only 33 cfs, discharged 3,700 ppd alkalinity to the West Branch. Mean concentrations of alkalinity, iron and sulfate were 20.5, 0.34, and 280 ppm respectively. The average load of alkalinity discharged to the West Branch from Chest Creek,

from all available data, is 12,200 ppd.

EPA mine discharge information indicates that spoil piles, coal refuse and abandoned deep mines contribute equally to AMD discharged in the watershed. During the EPA sampling period (72) Little Brubaker Run discharged 6,900 ppd acid to Brubaker Run. Three mine drainage discharges contributed 4,000 ppd acid to Little Brubaker Run. About 40 mine-drainage discharges were located in the Brubaker Run Watershed. At its mouth Brubaker Run was discharging 7,600 ppd acid to Chest Creek. In the Summer of 1970, Brubaker Run, with an average flow of 5.4 cfs, discharged 328 ppd alkalinity to Chest Creek. The DER did some surface restoration work in the Brubaker Run Watershed near the town of Hastings. During the Corps of Engineer sampling all tributaries to Chest Creek were found to be alkaline at their mouth, with Brubaker Run having the lowest pH. EPA sampling shows two tributaries--Wilson Run and Brubaker Run--to be acid, discharging 1,100 and 8,800 ppd respectively to Chest Creek. Listed below are tributaries of Chest Creek sampled by the Corps and their alkaline loadings, and mean concentrations of alkalinity and sulfate.

Tributary Name	Alkalinity ppd	Alkalinity ppm	Sulfate ppm
Brubaker Run	328	11.2	417
Pine Run	215	32.2	336
Kings Run	1,481	225	168
Camp Run	430	59	814
Spring Run	36	6.1	346
Snyder Run	50	6.5	22
Wilson Run	587	18.3	278

Since this sampling period, 1966-1968, water quality has improved throughout the watershed. Remaining AMD discharges are only affecting stream water quality on a local basis except for moderately high concentrations of sulfate type discharges which are widespread. Abatement of AMD in the Brubaker Run Watershed (12 square miles) could add needed alkalinity in the West Branch downstream from Clearfield Creek. Further mining activities should be planned so as to avoid stream water quality degradation in one of the few remaining non-acid streams in the headwaters region of the West Branch. Estimates of abatement cost for effective abatement projects are about 2.5 million dollars initially.

West Branch - Chest Creek to Clearfield Creek

Discussions of mine drainage originating within this reach of the West Branch will include all tributaries of the West Branch except Anderson Creek, which is discussed separately in the following section.

In this reach the West Branch meanders northeasterly from its confluence with Chest Creek near the town of Mahaffey to its confluence with Clearfield Creek just east of the town of Clearfield. This narrow reach of river is flanked mainly by Clearfield Creek Watershed to the southeast and Anderson Creek Watershed to the northeast. The West Branch and its tributary watersheds are underlain by wide spread deposits of Allegheny and overlying Conemaugh Group rocks.

This regions has been extensively deep and strip mined on both sides of the West Branch. Tributaries to the West Branch along this reach are not affected by AMD discharges as severely as most other areas in the West Branch sub-basin. AMD discharges affecting this reach of the West Branch occur mainly from Anderson Creek to Clearfield Creek on the north side of the West Branch.

Water quality information was obtained by the DER (50) during a sampling survey conducted from November 1970 to June 1972. Several small tributaries to the West Branch, between Chest Creek and the West Branch gaging station at Bower, contribute about 160 ppd alkalinity

to the West Branch. Data collected at the Bower Station shows that the average flow of the West Branch is 420 cfs. Values of pH average 7.1 and ranged from 5.8 to 7.6. Concentrations of alkalinity, sulfate, and total iron average 20, 195, and 5.1 ppm respectively. During tropical storm Agnes alkalinity dropped to its lowest recorded value of 6 ppm. Alkaline, sulfate, and iron loadings averaged 45,300, 441,000, and 11,500 ppd respectively. An additional thirteen tributaries discharge alkalinity to the West Branch between Bower Station and Curwensville. The only significant amount of AMD entering the West Branch in this reach was discharged by Mine Run, a tributary to the West Branch one mile southeast of Curwensville. When sampled Mine Run was discharging 780 ppd acid to the West Branch and had a pH of 3.2. Water quality data obtained by the DER on the West Branch upstream from Anderson Creek indicates that there is an overall improvement in water quality upstream from Bower Station. Alkaline concentrations increase slightly and average iron and sulfate concentrations are 0.2 and 170 ppm respectively. Large amounts of acidity and some additional alkalinity enters the West Branch, between Anderson Creek and Clearfield Creek. Downstream from Curwensville, Hartshorn Run discharges 330 ppd acid to the West Branch and has a pH of 3.8. One major deep mine discharge of 1700 ppd acid is responsible for poor water quality in the last mile of Hartshorn Run. Montgomery Run contributes 721 ppd acid to the West Branch. Strip and deep mines are the predominant

causes of pollution in Montgomery Run. The analyses of a sample taken by the DER indicated that Montgomery Run was discharging 600 ppd net acidity to the West Branch. Concentrations of AMD indicators were 4 ppm net acidity 0.1 ppm iron and 58 ppm sulfate. High flows during this sample period could account for the lower acid concentrations. Two additional tributaries contribu AMD to the West Branch just upstream from the confluences of Clearfield Creek and the West Branch. Moose and Wolf Runs contribute 75 and 1,100 ppd acid to the West Branch and have pH's of 3.6 and 3.1 respectively. Extensive strip and deep mining were conducted in these watersheds. The West Branch shows no detectable decrease in alkalinity and maintains a pH of 7.1 at Clearfield downstream from Moose Run.

Abatement of AMD in the Chest Creek-Clearfield Creek reach of the West Branch, excluding Anderson Creek, will primarily involve surface restoration. Abatement of AMD in this reach of stream will benefit a few small tributaries and increase the alkaline reserves or reduce acidity in the West Branch downstream from Clearfield Creek. Estimates of abatement cost are $2.5 million initially.

Anderson Creek

The headwaters region of Anderson Creek consists of Stony and Montgomery Runs, and Anderson Creek which flow into the Dubois Reservoir. These tributary streams are all in close proximity to underlying coal in Allegheny Group rocks. The tributaries flow west to southwest and lie south of the headwaters of both the Bennett Branch Sinnemahoning and Toby Creek, a tributary to the Clarion River. South of the reservoir, Anderson Creek flows southeast to its confluence with the West Branch at Curwensville. Parts of this reach of Anderson Creek are underlain by coal which is deposited in pockets to the east of Anderson Creek, and is even more wide spread to the west of Anderson Creek.

The major geological feature is the Chestnut Ridge Anticline which trends northeast-southwest passing through the Anderson Creek Watershed. This structural high exposed coal-bearing strata which has been removed by erosion in the eastern part of the watershed. Major structural features bounding the Anderson Creek Watershed to the southeast and northwest are the Clearfield Syncline and another syncline passing through DuBois respectively. All Allegheny Group coal bearing formations outcrop in the watershed, which also has rich deposits of associated clays.

Mining activities have been conducted mainly in the Little Anderson Creek Watershed which flows into Anderson Creek twelve stream miles from

its confluence with the West Branch. Clay mining, both deep and strip, has been carried out more extensively than in most other watersheds. Discharges of AMD emanate in equal amounts from both strip and deep mines.

At the mouth of Anderson Creek AMD indicators have mean concentrations of 46 ppm of acid, 148 ppm of sulfate, and 0.56 ppm of iron, and a pH of 3.9, and acid load of 2,600 ppd and a mean flow of 10.4 cfs. Flows ranged from 3.2 to 25.8 cfs during the EPA sampling period (72). An analysis of a sample taken in 1970 by the DER (50) during a high flow of 68.7 cfs, showed the pH increased to 4.3 and acid dropped to 26 ppm with an acid load of 9,600 ppd. Anderson Creek has a very low flow of 0.5 cfs upstream from Little Anderson Creek. Alkalinity, which steadily decreases downstream from the reservoir, is only 0.2 ppm. A pH of 5.2 was also recorded, indicating a slight influence by AMD from some mining upstream from Little Anderson Creek. Little Anderson Creek at its mouth has a mean flow of 2.65 cfs and discharges an average 4,200 ppd acid to Anderson Creek and renders the stream biologically sterile to its mouth. Mean concentrations of 290 ppm acid, 635 ppm sulfate, and 28.7 ppm iron were found at the mouth of Little Anderson Creek. Little Anderson Creek is acid from its headwaters to its mouth. The Creek discharges 200 ppd acid and has a pH of 3.9 only 1.5 miles downstream from the upper headwaters. Just south of the

village of Anderson, Rock Creek and a small tributary upstream from Rock Creek, discharge an amount of acid to Little Anderson that is nearly equal to all the acid in Little Anderson Creek. These two tributaries have four deep and strip mine discharges which total about 3,000 ppd acidity. One other discharge from a strip mine northwest of Chestnut Grove contributes an additional 1,500 ppd acid to Anderson Creek. A total of 4,500 ppd acid from five discharges to Little Anderson Creek exceeds the amount recorded at its mouth. About one mile from the mouth of Anderson Creek, Kratzer Run discharges 210 ppd acid to Anderson Creek. Kratzer Run Watershed has four major discharges of acid, totaling 1,800 ppd. These discharges emanate from strip mines located east and west of the town of Grampian.

The Anderson Creek Watershed is being studied by the DER (50) under contract SL 1-17:1-101.6. Information gathered during this study should provide the most realistic cost estimates of applicable abatement measures and their predicted effectiveness. Considering the information presently available, it would appear that abatement of AMD in Little Anderson Creek should realize the greatest benefits in the watershed. This would return utility to several miles of tributary stream, eight miles of Anderson Creek, and improve the West Branch. Abatement of AMD entering Kratzer Run would return utility to several miles of this tributary and insure alkaline

water quality in Anderson Creek to its mouth. A cost estimate of extensive surface restoration and a small follow up treatment facility should be about $4.1 million initially and $58,000 annually.

Clearfield Creek

Clearfield Creek enters the West Branch just east of the town of Clearfield in Clearfield County. Nearly the entire Clearfield Creek Watershed is underlain by coal. Four miles north of the village of Madera some small areas are void of coal. The headwaters of Clearfield Creek is located in the southeast corner of Cambria County near the town of Cresson. From Cresson Clearfield Creek flows mostly north to the village of Coalport. Here the Clearfield Creek turns and meanders northeast to Madera. From Madera, Clearfield Creek meanders north again, to its confluence with the West Branch east of Clearfield.

Two major geologic structures control drainage patterns, outcropping or exposure of coal, and the formation of MD. The first structure is a continuation of the Houtzdale Syncline, which passes through the town of Houtzdale, southeast to the town of Fallentimber, where it crosses Clearfield Creek. Formations containing coal seams are generally rising to the northwest and southeast from this axis. About 12 miles to the northwest rock units begin to level off and then dip to the northwest as they pass over the Laurel Hill Anticline, which trends northeast-southwest. In the southeast part of the Clearfield Creek Watershed rock units rise from the axis of the Houtzdale Syncline to the border of the Clearfield Creek and Juniata River Watersheds. The northeast end of the Laurel Hill Anticline

passes just southeast of the town of Bigler in the headwaters of Roaring Run. The axis trends southeast, passing in close proximity to Potts Run.

A substantial part of the Clearfield Creek Watershed is underlain by Allegheny and overlying Conemaugh Group rocks (77). All coal seams from the Clarion to the Upper Freeport are found in the Clearfield Creek Watershed. Recoverable coal reserves in the Clearfield Creek Watershed are estimated at 560 million tons (31).

Mining trends in the watershed are similar to other areas in the West Branch. Some extensive deep mine complexes exist, but deep mining never exploited the area to the extent existing in some parts of the Moshannon Creek Watershed. Deep mining was carried out more extensively, however, on the Lower Freeport seam "D" (figure 4), which in many areas, does not produce AMD. Many areas have been stripped, and as elsewhere, not reclaimed according to current law.

Some deep mines actually improve water quality in some areas and could be considered as an abatement technique. For example, one of the most extensive "B" seam deep mines in the Clearfield Creek area, northeast of Coalport, discharges relatively little mine water and little acid. The overlying "D" seam mine workings convey a significant amount of ground water from the hill, precluding its further infiltration and contact with the underlying "B" seam. Other areas in the Clearfield Creek

Watershed are not as severely affected by AMD as in the Moshannon Creek Watershed.

The following tributaries discharge significant amounts of AMD to Clearfield Creek. The following information is based on data collected for Operation Scarlift 1-73:1-101.7 conducted from July 1972 to December 1972 (31).

Tributary Name	Acid ppd	Acid ppm	Sulfate ppm
Trapp Run	1,600	50	200
Little Laurel Run	1,900	70	220
Bluebaker Run	1,200	50	160
Powell Run	4,000	100	250
Turner Run	700	24	300
Muddy Run	15,700	57	320
Japling Run	15,700	950	980
Pine Run	1,700	220	250
Lost Run	3,500	390	940
Upper Morgan Run	4,000	100	300
Potts Run	3,100	50	250
Morgan Run	1,600	100	320
Long Run	900	100	540
Roaring Run	4,200	60	280
Clearfield Creek (mouth)	57,000	50	250

The above data clearly shows two major sources of AMD. Muddy Run and Japling Run contribute about 50 percent of the AMD reaching the West Branch at the mouth of Clearfield Creek. Corps of Engineer data indicates an acid load of 61,000 ppd at the mouth of Clearfield Creek. At this point average concentrations of AMD indicators are 190 ppm of

acid, 273 ppm of sulfate, and 0.46 ppm of iron. The above-mentioned tributaries contribute an average of 59,000 ppd acid to Clearfield Creek. Krebs Run, Sanbourn Run and a few other tributaries contribute AMD to Clearfield Creek, all of which are neutralized by natural alkalinity between their entry and the mouth of Clearfield Creek.

Water quality along Clearfield Creek varies from the headwaters to its mouth. Upstream from Trapp and Bradley Runs, Clearfield Creek has an average of 6 ppm alkalinity, but has a clear indicator of mine drainage with its average 120 ppm sulfate. Clearfield Creek remains wealkly alkaline north to the town of Madera. Above Little Laurel and Brubaker Runs, Clearfield Creek becomes slightly acid, however, during high flows the Creek may return to alkaline condition. Average concentrations of acid above Brubaker Run are 6 ppm. At a point just downstream of Powell Run, Clearfield Creek is weakly acid or alkaline, depending upon flow. Immediately upstream from Powell Run, Clearfield Creek becomes slightly acid with an average 20 ppm. Further upstream Clearfield Creek receives both moderately alkaline and slightly acid discharges from a number of small tributaries (their net effect is recorded at the town of Irvona). Here Clearfield Creek has an average pH of 5.9 and a concentration of 6 ppm alkalinity. Some considerations are currently being given to the stocking of smallmouth bass in this alkaline reach of stream. Clearfield Creek remains slightly alkaline to a point just south of Madera. South of

Madera, Clearfield Creek begins to undergo rapid water quality degradation which continues to its mouth. South of Madera, Clearfield Creek is first affected by deep mine discharges along Route 53 which enter Clearfield Creek at several locations. Clearfield Creek receives an average of 15,700 ppd acid from its second largest tributary, Muddy Run. Muddy Run's largest source of AMD is the Brookwood Shaft (33), a large deep mine in "E" seam discharging an average 17,300 ppd to Muddy Run. Average acid, sulfate and iron concentrations of this discharge are 640, 1,500, and 60 ppm respectively. Elimination of acid discharging from the Brookwood Shaft alone would eliminate acidity at the mouth of Muddy Run, and reduce the acid load at the mouth of Clearfield Creek by 34 percent. Muddy Run Watershed has four other deep mines with a combined discharge of 9,000 ppd acid. Two deep mine discharges contribute 3,400 ppd alkalinity to Muddy Run. The main stem of Muddy Run is polluted from its headwaters to its mouth. Data quoted here was obtained from an extensive AMD study conducted in the Muddy Run Watershed under the Department's Project SL-155 (33). The DER is currently doing surface reclamation work in the Muddy Run Watershed.

Just downstream from Muddy Run, Japling Run discharges large quantities of acid, and is Clearfield Creek's last major source of AMD. Clearfield Creek undergoes further water quality degradation between Pine and Japling Run where it has average concentrations of 60 ppm acid, 250

ppm sulfate, and 17 ppm total iron. Values of pH average 3.7 and range from 3.4 to 3.9. Pollution discharged from Pine Run and Lost Run prevents Clearfield Creek from improving in this reach of stream. The Lost Run Watershed differs from most other watersheds in the West Branch due to its high acid production from strip mines alone. The DER is currently planning extensive surface restoration work for Lost Run. Downstream from Potts Run and Morgan Run, Clearfield Creek's water quality continues to improve slightly with an average acidity of 47 ppm and an average pH of 4.0. Water quality information indicates that Clearfield Creek improves only slightly from Potts Run to the mouth. In this reach acid and alkaline contributions equal one another.

Some abatement work could be done in the Trapp Run-Turner Run reach to assure predominantly alkaline flows even during low flow conditions. This reach of stream would then support recreational activities. Muddy Run and Japling Run will require a combined 90 percent abatement effectiveness in order to return utility to Clearfield Creek and improve the water quality of the West Branch. Estimates of abatement cost required to return the mainstream of Clearfield Creek to a non-acid condition are placed at $17.4 million initially and $400,000 annually. This work will reduce the acid load of the West Branch by 26 percent and could provide significant amount of alkalinity during moderate to high flows.

West Branch - Clearfield Creek to Moshannon Creek

The West Branch flows mostly east to northeast from Clearfield Creek to Moshannon Creek, a distance of about 32 stream miles, dissecting Allegheny Group rocks and associated coals underlying nearly all watersheds tributary to the West Branch from the south, except for a large area drained by Moravian Run. On the north side of the West Branch nearly all tributaries are underlain by coal near their confluence with the West Branch. Lick Run, Trout Run, Moravian Run, Deer Creek, and Sandy Run have large areas in their headwaters (outside major coal seams) which is reflected by relatively lower concentrations of AMD indicators at their mouths.

Sixteen tributaries of the West Branch in this reach contribute a total of 71,100 ppd acid to the West Branch. Alder Run alone contributes 21 percent of this acid load (30), and about half of these tributaries are responsible for 84 percent of the acid load. Most AMD is discharging from numerous deep mines which have their flow augmented by strip mines. Nearly all areas underlain by coal have been extensively strip mined, and many square miles of watershed are nearly void of plant life. Watersheds tributary to this reach of the West Branch have a mining history similar to the Clearfield County side of Moshannon Creek. Many deep mines extend from the Moshannon Creek area into Alder Run and adjacent watersheds.

Under the former Department of Mines and Mineral Industries Project SL-143 (30) an AMD study was performed in the Alder Run Watershed which provides information applicable to other watersheds in the area. Portions of this study's findings are given here.

Two major geologic structures trending northeast-southwest pass through this area, the Laurel Hill Anticline on the south side of the West Branch, and the Clearfield Syncline on the north side of the West Branch. An area of minimum and maximum fold amplitude exists in the southwest and northeast ends of this reach of the West Branch respectively. Approximately the same coal seams found in the Moshannon Creek Watershed underlie this area, namely the Clarion "A" (figure 4) seam to the Upper Freeport or "E" seam. The Clarion "A" to Upper Kittanning "C'" seams predominate.

Water quality information provided by the EPA is presented below. The following tributaries are the most significant contributors of AMD to this reach of the West Branch.

Tributary Name	Drainage Area Sq. Mi.	Average Acid ppd	Average Acid ppm
Abes Run	2	1100	295
Lick Run	31	1700	35
Trout Run	40	1900	34
Millstone Run	4	3800	361
Surveyor Run	5	2300	230
Murray Run	1	1300	1340
Congress Run	1	7500	2370
Moravian Run	18	1600	58
Deer Creek	19	5600	126
Sandy Creek	19	5200	171
Alder Run	22	15000	690
Rolling Stone Run	4	3600	1030
Basin Run	5	8600	444
Rock Run	3	4500	800
Potter Run	4	6300	796
Rupley Run	2	1100	1170

As is also true of the tributaries to the West Branch immediately upstream from Moshannon Creek, those streams which have extensive hea water regions not underlain by coal have the lowest concentrations of AMD indicators. In the Clearfield-Moshannon Creek reach, as expected, Lick Run, Trout Run, Moravian Run, and Deer Creek are low in acid (ppm) relative to other tributaries which have seen comparable mining activities on similar seams. Three of the above mentioned four tributaries contribut relatively low acid loads to the West Branch. AMD abatement work in thes three tributaries will not contribute greatly to restoration of the West Brar however, it may be possible to return a water quality to these tributaries which is suitable for the support of fish life. The remaining tributaries lis

above are severely polluted and have relatively little recreational potential, especially Alder Run (30). Abatement work in these tributaries can, however, contribute greatly to cleaning up the West Branch. Water quality information obtained from Penelec's Shawville Generating Station (31) gives an excellent account of yearly changes of pH and flow in this reach of the West Branch. During the winter to early spring period, both average flow and pH decrease. Values of pH, which fluctuate very little, decrease from 6.0 to 5.2. From spring through summer, flows continue to decrease to a minimum at the end of August, where pH generally fluctuates from 4.6 to 5.3. The average flow for the year is about 600,000 gpm or 1340 cfs. During the summer, flows decrease to an average of 200,000 gpm. Detailed inspection of the Shawville data indicates that slugging occurs during peak flows and then as flows decrease pH increases.

During project SL-143 an average of 16,500 ppd acid was measured discharging to the West Branch from Alder Run. This compares well with the 15,000 ppd obtained by EPA and supports other EPA (72) data collected along this reach of the West Branch. Practically no natural sources of alkalinity were found in the Alder Run Watershed. During the study (30), each of 7 deep mine outfalls was found to be discharging over 1,000 ppd acid to Alder Run. The lack of natural alkalinity will limit the success of preventive abatement measures, since alkalinity will not be available to

neutralize small uncontrollable amounts of AMD which remain.

Some treatment may be justifiable in this reach of watershed or in the Moshannon Creek Watershed since sufficient abatement, to return recreational potentials to the West Branch, does not appear possible using known preventive measures. Reductions of AMD in this reach of the West Branch will also depend greatly upon what is achieved in the Clearfield Creek Watershed and other selected areas in the headwaters of the West Branch.

The DER has done and is currently doing extensive surface restoration work in Alder Run, the greatest discharger of AMD to the West Branch in this reach. Providing some mine sealing is feasible, the estimated cost of abatement work for the entire area, including extensive surface restoration, is placed at 18 million dollars initially. The maximum percentage reduction of AMD, using conventional preventive abatement measures, is estimated at 40 percent. This value may increase somewhat if mine sealing can be employed more successfully than anticipated. The above costs do not include treatment which could be justifiable in this reach of the West Branch.

Moshannon Creek

The Moshannon Creek Watershed drains 288 square miles in eight townships in Centre and Clearfield Counties. The watershed has a maximum width of 13 miles and a length of about 30 miles from the Blair-Centre County line northeast to the West Branch just 3 miles southwest of Karthaus. Only few tributaries which have their headwaters in the high plateau region along the southeast edge of the watershed possess water quality suitable for sport fishery. Most tributaries on the northwest side of Moshannon Creek are seriously degraded by AMD.

Severe degradation of Moshannon Creek and its tributaries is mainly the result of extensive deep mining which began in the early to mid-1800's. Deep mining was undertaken on the southeast side of Moshannon Creek from its headwaters to Black Bear Run 6 miles northeast of Philipsburg. Deep mining of both coal and clay was also carried out in an area that extends 6 miles southwest and northwest from the town of Moshannon and in areas bordering the Beech Creek Watershed to the northeast of the town of Moshannon. The entire northwest side of Moshannon Creek is underlain by coal and has been extensively deep mined from its headwaters downstream to Crawford Run. Nearly all areas which were deep mined were also extensively strip mined.

Mining of highly pyritic, near surface, coal produced considerable amounts of highly concentrated AMD. A small isolated coal basin underlying the Mid-State Airport does not account for any appreciable degradation of water quality in Black Moshannon Creek.

The Moshannon Creek Watershed is underlain by the following coal seams: (from bottom to top) the Clarion "A", Brookville "A", Lower Kittanning "B", Middle Kittanning "C", Upper Kittanning "C'", Lower Freeport or the high quality Moshannon Coal "D", and the Upper Freeport "E" seams (figure 4). In the past, all seams were deep mined where possible. The most extensively deep mined seams were the "A", "B", and "D" seams, which were three to five feet thick and of good quality (77). The "D" seam is generally the highest quality coal in the watershed and in many areas does not produce AMD. The "A" coal is the only seam presently being deep mined in one area east of Osceola Mills. The small reserves of the "E" and "D" seams are presently being strip mined with little production of AMD. Both the "A" and "B" seams (sometimes split "B") are being stripped where their sulfur and ash content are sufficiently low or where blending of higher quality coals is possible. In the past active strip and deep clay mines were more numerous. Presently, little clay remains which is of proper quality and less clay mining is being done. Although clays are widespread in the Moshannon Creek Watershed, high quality clays, low in iron and silica only occur locally.

The following geologic aspects of the Moshannon Creek Watershed greatly affect drainage patterns and AMD production. The axis of the Moshannon Anticline trends along the middle of the southeast side of the Moshannon Creek Watershed. To the northwest, the axis of the Houtzdale Snycline is located in close proximity to Moshannon Creek and plunges slightly to the southwest. Both the "A" (Clarion) and "B" (Lower Kittanning) seams outcrop along most of Moshannon Creek and its tributaries. Extensive deep mine workings, predominantly on the "B" seam and somewhat less on the "A" seam, drain large amounts of AMD directly to Moshannon Creek and most of its tributaries. An area of high AMD productivity exists between Hawk Run and Grassflat Run on the northwest side of Moshannon Creek. In this region, pyritic material associated with the coal have been extensively deep mined, consequently this region has many large deep mine discharges of AMD.

The Houtzdale Syncline is paralleled by the Laurel Hill Anticline to the northwest, which in some areas is the approximate northwest boundary of the Moshannon Watershed (bordered by Clearfield Creek and several tributary watersheds flowing directly to the West Branch.)

An AMD study (31) was conducted in the Moshannon Creek Watershed under part of the DER's Project SL 1-73:1-101.7. Portions of the findings are reported below. The following water quality data was

collected after tropical storm Agnes during a sampling period (31) which extended from July 1972 to December 1972. Moshannon Creek also has numerous direct sources of AMD in addition to its tributary stream sources. All tributaries, from the headwaters to the mouth of Moshannon Creek, were contributing the following average concentrations and loadings of AMD.

Tributary Name	Net Acidity ppd	Acid ppm	Sulfate ppm
Whiteside Run	1,900	85	220
Mountain Branch	281	8	53
Bear Run	2,275	158	242
Coal Run	3,720	142	344
Beaver Run	2,165	65	286
Big Run	4,174	222	518
Trout Run	3,663	74	213
Little Laurel Run	4,941	90	290
Laurel Run	7,552	82	322
Emigh Run	913	56	255
Cold Stream	1,637	48	160
One Mile Run	7,954	1189	1186
Hawk Run	13,651	390	532
Sulfur Run	27,550	1219	1230
Grassflat Run	6,328	597	1130
Moravian Run	6,800	421	834
Bk. Moshannon Crk.	900	7	26

"Operation Scarlift" data (31) indicates that Moshannon Creek contributes 95,900 ppd acid to the West Branch with an average flow of 93 cfs. Average concentrations of AMD indicators are 190 ppm of acid, 357 ppm of sulfate, and 0.41 ppm of iron. Upstream from the mouth of Moshannon Creek, the

West Branch has an acid concentration of 43 ppm and downstream from the mouth of Moshannon Creek water quality is degraded to 70 ppm acid. Comparisons of EPA and Scarlift data indicate that most tributaries have improved their water quality or never had average acid concentrations quite as high as formerly recorded. However, Moshannon Creek is still the most polluted tributary of the West Branch.

From the headwaters to the mouth of Moshannon Creek, the following AMD conditions cause extreme pollution within the watershed. Upstream from Whiteside Run, Moshannon Creek's waters are moderately polluted and have acid concentrations averaging 35 ppm with a pH of 4.1. Iron and sulfate concentrations average 5.8 and 140 ppm respectively. Downstream from Bear Run the average acidity of Moshannon Creek has doubled (mainly in response to Whiteside and Bear Run's AMD contributions). Between Bear and Trout Runs, Moshannon Creek receives its first major input of AMD. On the south side of Moshannon Creek a large hill between these two tributaries contains both "A" and "B" seam deep mines discharging significant amounts of AMD. Precipitation is the only source of water to the hill. This water enters the hill mainly through 1,457 acres of strippings which occupy 35 percent of the hill's area. During the summer of 1972, this area contributed 2,400 ppd acid to Bear Run, which is 55 percent of the total acid load of 4,400 ppd recorded during this time at the mouth of Bear Run.

This area was also the source of 4,000 ppd acid to Trout Run. Other major deep mine discharges from this hill contribute acid directly to Moshannon Creek. Southeast of Osceola Mills a large number of air seals and seepages from "A" and "B" seam deep mine workings contribute, at times, nearly 10,000 ppd acidity to Trout Run. Just upstream from Cold Stream (in Philipsburg) Moshannon Creek water quality continues to be degraded. Average concentrations of acid, sulfate, and iron are 120, 340, and 12.0 ppm respectively. Between Little Beaver and Coal Runs Moshannon Creek also increases in water quality degradation.

Between Hawk Run and Grassflat Run, Moshannon Creek receives its largest discharges of AMD, some of which is contributed from the southeast side of Moshannon Creek between Cold Stream and Black Bear Run. Discharges of AMD mainly from large deep mine complexes in this area cause the most severe pollution found in Moshannon Creek. Concentra-trations of acid in Moshannon Creek average about 250 ppm downstream from Sulfur Run. Farther downstream concentrations of acid decrease slightly in response to alkaline flows from Six Mile Run and a few other tributaries not underlain by coal in this reach. Water quality degradation in the Hawk Run to Grassflat Run area is also caused by widespread coal refuse along flood plains and abandoned tipples. Upstream from Black Moshannon Creek average concentrations of acid are still high at 220 ppm. Several

tributaries on the northwest side of Moshannon Creek from Grassflat to Weber Runs are responsible for this condition. Downstream from Black Moshannon Creek, the Moshannon Creek's water quality improves continually to its mouth.

Nearly total abatement of AMD in the Moshannon Creek Watershed, at this time, will not be possible. There are numerous large discharges from drifts, blow-outs, air seals and seepages which are difficult to control or prevent to any predictable extent. Mine sealing will only be possible on a very limited basis due to stripped crop barriers, great differences between the elevations within the mines, and incomplete or false recordings of deep mine developments.

Abatement cost for nearly 90 percent effectiveness would be prohibitively high and probably unrealistic. In only a few cases would abatement of AMD benefit Moshannon's tributaries alone. Black Moshannon Creek and Mountain Branch, for example, could be returned to a quality suitable for fishing. This could be accomplished by channel diversion of AMD directly to Moshannon Creek or AMD abatement measures. The major justification of AMD abatement expenditures will come from benefits realized on the West Branch. Preventive abatement measures, estimated to cost 12 million dollars, could abate 25 percent of Moshannon Creek's AMD.

West Branch - Moshannon Creek to Sinnemahoning Creek

Downstream from the confluence of Moshannon Creek, the West Branch meanders northeasterly to its confluence with the Sinnemahoning Creek in the northeast corner of Centre County. Along this reach of stream, tributaries to the West Branch drain large areas underlain by bituminous coal. On the northwest side of the West Branch, areas underlain by coal extend from Moshannon Creek to Sinnemahoning Creek. On the southeast side areas underlain by coal extend only from Moshannon Creek as far as Sterling Run. Downstream from Sterling Run, the West Branch receives gradually improving alkaline discharges ranging in pH from 6.5 at Spruce Run to 7.5 at Burns Run. The main body of coal which mostly affects the northwest side of the West Branch extends across Sinnemahoning Creek to Renovo and also affects Kettle Creek.

Very limited strip mining has been undertaken on the southeast side of the West Branch relative to the northwest side which has been extensively stripped from Mosquito Creek to Little Birch Island Run three miles northeast of Pottersdale. Northeast of this tributary stripping has only been undertaken at high elevations (1600 feet) in small isolated areas. Mining activities have not significantly affected tributaries from and including Little Birch Island Run to Sinnemahoning Creek. The following tributaries contribute acidity (72) to the West Branch in this reach.

Tributary Name	Acid ppd	Acid ppm	pH
Mosquito Creek	---	----	4.6
* Laurel Run	120	14.8	4.2
Saltlick Run	890	76.0	3.4
Upper Three Runs	450	13.7	4.5
Lower Three Runs	170	3.2	5.1
* Sterling Run	100	1.0	4.6
Loop Run	700	110	3.2

* Denotes tributaries entering the West Branch from the southwest.

The above tributaries have been extensively strip mined in their headwaters. Saltlick and Loop Runs are the highest in acid concentrations and have relatively small watersheds underlain by coal. These watersheds are completely enclosed by stripped lands, the source of the highly acidic and low pH water quality. Other watersheds, namely Upper and Lower Three Runs, and Mosquito Creek have been stripped as extensively, however, their headwaters drain areas, outside the coal beds, which provide alkalinity that neutralizes most of the acidity. Several of these tributaries are stocked by the Fish Commission in their headwater regions.

At a time when pH's were ranging from 5.5 to 6.0 in the West Branch between Moshannon and Clearfield Creeks, the following water quality existed downstream in the West Branch at Karthaus. Acid, iron, and sulfate concentrations were 71, 4.7 and 180 ppm respectively with a pH of 3.8. These water quality conditions are mostly in response to Moshannon Creek's exceedingly high AMD loadings. Very little is actually known about the area

between Moshannon and Sinnemahoning Creeks. Information on mine drainage locations and their characterization is not available. Relatively small amounts of acid mine drainage are contributed by these streams to the West Branch. Therefore, justification for abating AMD in the affected tributaries must be developed from the benefits derived within the tributary watersheds, and not from the West Branch (where their effects are essentially zero). Tributaries that have extensive and far-reaching headwaters which accumulate alkaline reserves have the greatest possibilities for sufficient AMD reduction to return the streams to some beneficial use. Estimated cost of abatement, in five of the seven watersheds with low concentrations of acidity, is about 5 million dollars initially.

Sinnemahoning Creek

The Sinnemahoning Creek, with its 1,032 square mile drainage area, is the largest tributary to the West Branch of the Susquehanna. The Sinnemahoning Creek Watershed is comprised of three large tributaries, the First Fork, Bennett Branch, and the Driftwood Branch. Topographic and geologic conditions in the watershed combine to produce "flash" flows with low drought flows and low natural alkalinity reserves in the streams.

Only a small part of the Sinnemahoning Creek Watershed is underlain by coal deposits. Most coal deposits are located in the Bennett Branch Watershed, with most of the reserves close to its headwaters. The northeast part of the Driftwood Branch basin is also underlain by coal deposits. Sterling Run contributes AMD to the Driftwood Branch but does not overcome its alkaline reserve. The First Fork is not affected by AMD (72). The Bennett Branch is acid from Moose Run to its mouth. In turn it renders the Sinnemahoning Creek acid from their confluence to the point where the Sinnemahoning Creek joins the West Branch.

Recent data indicates that the following tributaries to the Bennett Branch are significantly affected by AMD (69, 71, 72). Those tributaries are (from headwaters to the mouth) Moose Run, Mill Run, Tyler Run, Cherry Run, Kersey Run, Laurel Run, an unnamed tributary to the Bennett Branch downstream from Caledonia, and Dents Run. Of the above mentioned tributaries,

only Dents Run has received an extensive AMD study. The remaining tributaries will be partially judged on the basis of knowledge gained from the Dents Run study and other "Operation Scarlift" studies conducted by the DER in the West Branch area. The Dents Run study was conducted for one hydrologic year when an annual record of flow behavior and stream loadings was compiled. Other sources of data, both past and recent, were usually collected during relatively low flow conditions. Therefore, low measurements of the AMD potential of Dents Run, among other tributaries to the Bennett Branch, were made.

An AMD study (9) was conducted in the Dents Run Watershed of the Bennett Branch Sinnemahoning under the DER's Project SL-161. Information contained in the Dents Run Report is evaluated here for its applicability to other tributaries of the Bennett Branch for which similar information was not available. Dents Run field investigations were conducted from January 1971 to January 1972.

The Dents Run Watershed drains an area of 36.0 square miles located mainly in Elk and part of Cameron Counties about 12 miles southeast of St. Mary's. Elevations range from 926 feet near the mouth of Dents Run to 2,240 feet in the headwaters. This part of the Allegheny Plateau has been deeply eroded by Dents Run and its tributary streams, and is characteristic of other steep sloped areas along the Bennett Branch.

Major tributaries of Dents Run are Dark Hollow, Bell Draft, Shaffer Draft, McDonald Run, Little Bear Run, Porcupine Run, Porcupine Hollow and Cole Draft. Porcupine Hollow is the only tributary which has had its natural drainage pattern extensively altered by mining. Rock units, also outcropping elsewhere in the Sinnemahoning Watershed, are Devonian, Mississippian, and Pennsylvanian in age - all belonging to the Paleozoic Era. Coal seams in the area range from the Mercers to the Clarion and Lower Kittanning, a total of six seams One structural feature, the Caledonia-Pine Creek Syncline, controls ground water movement and gravity drainage from deep mines in the Dents Run Watershed. The close proximity of the axis of this syncline to Porcupine Hollow is responsible for its severe water quality degradation.

Small mining operations began in the late 1800's (9) and consisted of only small pits and drifts. In the 1900's "room and pillar" methods were used in extensive deep mine operations. Since the 1940's most coal was mined by stripping methods. Only a limited area within the Dents Run Watershed was strip mined, mainly in the Porcupine Hollow area south of the Dents Run mainstream. Deep mining was also carried out in this area which serves as a common collection point for all subsurface drainage.

Analyses from extensive sampling showed that only three tributaries

of Dents Run contained heavy concentrations of AMD indicators. The first tributary, Porcupine Hollow, draining 1,668 acres, contributes 14 percent of Dents Run's flow and conveys an amount of acid equal to 100 percent of Dents Run's AMD loading. Six deep mine portals discharge appreciable amounts of AMD. Of the total 425 acres of stripping found in Porcupine Hollow, 200 (as of 1972) were active. Another severely polluted stream in the Dents Run Watershed is Cole Draft. It has a smaller drainage area of 0.9 square miles. About 90 acres of old strip mines exist in its upper headwaters and are the main source of AMD pollution. Porcupine Run (not to be confused with Porcupine Hollow) is the only other severely polluted stream in Dents Run.

The results of stream flow and water quality analysis indicate that Dents Run, with an average pH of 3.3 and an average flow of 6.8 cfs, contributes average acid, sulfate, and iron loadings of 4,300, 100, and 13,100 ppd respectively to the Bennetts Branch. Three tributaries of Dents Run contribute the following AMD loadings to Dents Run: Porcupine Hollow - an average pH of 2.75 and an average flow of 1.3 cfs contributes 4,400 ppd of acid, 500 ppd of iron and 13,700 ppd of sulfate to Dents Run. Porcupine Run - with an average pH of 3.3 and an average flow of 0.34 cfs contributes and average 177 ppd of acid; 11 ppd of iron and 950 ppd of sulfact to Dents Run. Cole Draft - an average pH of 4.1 and an average flow of 0.48 cfs

contributes an average 227 ppd of acid, 1 ppd of iron and 1,617 ppd of sulfate to Dents Run. Dents Run upstream of Porcupine Hollow and Porcupine Run has relatively good water quality. There are 4 major sources, all in Porcupine Hollow, and about 21 minor sources of AMD contributing to the above stream loadings. Three of the four major sources are abandoned deep mines, and one was an active strip mine. Of the 21 minor sources, 15 are in Porcupine Hollow. Minor sources of mine drainage are almost equally divided among deep mine and coal refuse discharges.

Abatement of AMD discharging from deep mines with mine seals or treatment methods will be utilized on a limited basis. Differences of elevations in mine workings range from 112 to 254 feet. Complete inundation of mine workings could create heads which could break seals or cause AMD breakouts elsewhere. Treatment would only be recommended as a possible follow-up method after economically feasible preventive measures were applied to the fullest extent required. Preventive measures appear most applicable since they will improve water quality. They will increase surface runoff and decrease infiltration, resulting in decreased deep mine discharges. Restoration of bony refuse dumps was also recommended in Dents Run.

Abatement priorities were established for numerous coal refuse dump reclamation projects having a total estimated cost of $171,000.

Strip mine reclamation priorities were also established for 15 projects with estimated costs placed at 2.8 million dollars. Recommended abatement is expected to result in a 56 percent reduction of AMD in Dents Run. The estimated cost per acre established by the consultant was about twice the average cost of strip mine reclamation work elsewhere in the Bituminous Fields. The authors of this paper have reduced the estimated cost for reclamation and follow up treatment to 2 million dollars initially and 50,000 dollars annually for complete abatement of AMD in the Dents Run Watershed. This cost estimate is in close agreement with current reclamation costs.

Other sources of flow measurements and water quality data for the mouth of Dents Run indicate average flows of 3.3 cfs or only 0.132 cfs per square mile of drainage area. Operation Scarlift information (9) indicates that average flows are closer to 7.0 cfs, a value which would be more realistic considering a drainage area of 36 square miles. Information gathered during the Dents Run study indicated that only small changes in the concentration of AMD indicators were noticed with changes in flow. Water quality information for other affected streams tributary to the Bennett Branch indicate that Moose Run and Laurel Run increase in acid load with increasing flow. Both Tyler Run and an unnamed tributary at Caledonia have nearly constant acid ppm with changing flows. Mill Run,

Cherry Run and Kersey Run have decreases in acid load with increasing flow. Increases in concentrations of acid during high flow usually indicate abundant sources of acid-forming materials which can produce AMD quite readily. These conditions usually exist in the form of refuse piles along flood plains, mine pools which overflow during moderate to high flows, and strip pits which can be flushed during wet periods.

Bennett Branch, at its mouth, has a pH of 3.45 with acid, iron, and sulfate concentrations of 58, 0.35 and 149 ppm respectively. At its mouth Bennett Branch discharges 23,000 ppd acid to the Sinnemahoning Creek based on the best information available. The Bennett Branch upstream from Dents Run has acid concentrations similar to those at its mouth. Downstream from the unnamed tributary at Caledonia the acid concentration in the Bennett Branch doubles to 120 ppm in response to this tributary's acid load of 7,800 ppd. The Bennett Branch remains highly acid from Caledonia to Mill Run. The acidity of the Bennett Branch decreases above Mill Run. Downstream from Moose Run, the Bennett Branch becomes slightly acid with a pH of 5.0 and acid concentrations of only 20 ppm. Above Moose Run, which has acid concentrations of 140 ppm, the Bennett Branch is alkaline with pH's ranging from 7.1 to 7.8.

PRINCIPAL MINE DRAINAGE CONTRIBUTORS TO
BENNETT BRANCH SINNEMAHONING CREEK

Tributary	Stream Mile on Bennett Branch	Drainage Area sq. mi.	Net Acid Load ppd
Moose Run	34	2	2,200
Mill Run	32	2	370
Tyler Run	31	8	1,800
Cherry Run	29	5	540
Kersey Run	27	27	470
Laurel Run	25	50	357
Unnamed Trib. at Caledonia	24	4	7,800
Dents Run	11	36	4,300

Relatively few mine drainage discharges emanate from strip mines directly. Strip mines do, however, augment deep mine discharges in a number of cases. Information available for major AMD discharges indicates that the above mentioned tributaries contributing mine drainage to the Bennett Branch are primarily affected by abandoned deep mine discharges associated with stripped land. Often deep mines were opened by strip cuts or the crop barriers were weakened or fractured.

Currently the DER (50) is conducting an AMD study under contract SL-195 in the Bennett Branch Watershed from Moose Run to Dents Run. Water quality data listed below is based on averages calculated from July and August sampling. Sampling was conducted during periods of low flow which accounts for a total of only 9,200 ppd acid being contributed from the twelve tributary sources listed below. Based on other sources of AMD

data in the Sinnemahoning Creek area, it is probable that yearly average loadings of acid contributed by these tributaries should approach a total of 25,000 ppd.

Tributary Name	pH	Acid ppm	Acid ppd	Sulfate ppm	Sulfate ppd
Moose Run	3.1	156	760	800	3900
Mill Run	3.6	100	600	170	1000
Tyler Run Reservoir	3.3	160	1150	300	2166
Tyler Run	3.5	100	140	230	320
Unnamed Tributary at Scattertown	3.4	110	130	270	320
Cherry Run	3.8	55	900	150	2970
Kersey Run	4.7	6	720	35	4200
Unnamed Tributary at Caledonia	2.9	300	3200	500	5390
Bell Hollow Tributary to Laurel Run	3.6	75	440	250	1480
Spring Run Tributary to Trout Run	6.0	3	180	35	2100
Trout Run	5.9	5	900	80	14400
Unnamed Tributary at Mt. Pleasant Church	3.4	180	60	600	194

The results of the DER's Bennett Branch study should more fully characterize and quantify the watershed's AMD problems and offer insights to applicable abatement methods and their cost estimates. This information supplemented by knowledge gained during the Department's Dents Run AMD study should be consulted for a more accurate appraisal of individual tributary watershed priorities within Sinnemahoning Creek Watershed.

Abatement measures applicable in the Bennett Branch will compare well with those recommended for the Dents Run Watershed. Extensive surface restoration, use of low flow augmentation and follow up treatment of acidity, for nearly total abatement, is estimated to cost $10.5 million initially plus $400,000 annually.

West Branch - Sinnemahoning Creek to Bald Eagle Creek

Downstream from the confluence of the West Branch and the Sinnemahoning Creek the West Branch flows northeasterly along the southeastern edge of the bituminous coal field. This area, underlain by coal, extends from the Sinnemahoning Creek to the town of Renovo (10 miles) and has a maximum width of about 5 miles. Downstream from Renovo the West Branch flows southeast through areas devoid of coal bearing formations. Just southeast of the town of Glen Union the West Branch passes through a small extension of the bituminous field which contains small isolated pockets of coal. Downstream from the confluence of the West Branch and Tangascootack Creek the West Branch leaves the coal measures and flows southeasterly to its confluence with Bald Eagle Creek southeast of Lock Haven.

Along this reach of the West Branch the River maintains the same water quality. Mine drainage originates in a small area of intense mining activity near the mouths of Cooks Run, Milligan Run, and Kettle Creek. Crooks Creek receives mine drainage from Crowley Hollow Run, a major tributary of Cooks Run, about one mile from its mouth. Crowley Hollow Run is affected by four deep mine discharges each in excess of 1,000 ppd (72). The only water in the right fork or Nefeur Hollow Run, a tributary to Crowley Hollow, comes from an old deep mine drift portal

discharging 1,400 ppd acid. Crowley Run also receives a 4,500 ppd acid discharge from a mine seal. The last two deep mine discharges of 1,900 and 3,900 ppd acid (72) emanate from old, deep mine drift entries on the west side of Crowley Hollow. Crowley Hollow has an average pH of 2.6 and discharges an average 9,100 ppd acid to Cooks Run. Cooks Run discharges 8,200 ppd acid to the West Branch.

One quarter of a mile downstream from Cooks Run the West Branch receives an average 1,000 ppd acid from Milligan Run. All sources of AMD to Milligan Run emanate from old drifts. About 2,200 ppd acid is discharging from five deep mine drifts. Flows are abnormally low in the Milligan Run Watershed probably due to underground diversion of water to Kettle Creek or Cooks Run. The small flow from Milligan Run has no significant effect on water quality in the West Branch.

Kettle Creek is the largest tributary to the West Branch in this reach, and it is the last downstream, direct, and significant source of AMD to the West Branch. At its mouth Kettle Creek has a mean pH of 4.0 and a mean acidity of 21 ppm. An average flow of 83 cfs discharges 10,000 ppd acid (72) to the West Branch. Kettle Creek is only degraded by AMD for about four stream miles upstream from its mouth. Throughout most of its length, Kettle Creek flows through heavily forested land and is considered an excellent trout stream. Just upstream from the first AMD discharges

Kettle Creek has a mean pH of 6.2 and alkaline concentrations of only 20 ppm.

Kettle Creek first receives over 4,000 ppd acid from three deep mine discharges. Just upstream from the confluence of Kettle Creek and Two Mile Run, Kettle Creek receives another 6,400 ppd acid from three major deep mine discharges. Huling Run, Two Mile Run and Butler Hollow, tributaries to Kettle Creek discharge 5,200, 6,000, and 750 ppd acid to Kettle Creek respectively. Deep mines account for all major sources of AMD in these tributary watersheds. There are a total of eleven discharges, averaging 1,800 ppd acid each, in the Kettle Creek Watershed.

During recent investigations of the West Branch in the Kettle Creek area, under the DER Project SL-115, it was determined that Kettle Creek, Milligan Run, Crowley Hollow Run, and North Smith Run were contributing 60, 12, 24, and 4 percent respectively of the AMD to the West Branch in this reach. These tributaries are listed below with their mean loadings of acid, iron, and sulfate.

Tributary Name	Acid ppd	Iron ppd	Sulfate ppd
Kettle Creek	44,150	4,800	54,000
Milligan Run	11,700	1,700	14,600
Crowley Run	32,500	4,500	32,600
North Smith Run	300	12	130

These figures indicate that 45 tons of acid per day are being discharged to the West Branch during average flows. Sulfate loadings would more realistically correspond with a total acid load of 17 tons per day. Acid and sulfate load ratios are more commonly 1:3 and this excess acid may be from natural sources and not from CMD.

Just west of Renovo, Drury Run discharges 200 ppd acid to the West Branch. Drury Run does not undergo extreme water quality degradation. At the mouth, Drury Run has a mean pH of 5.0 and mean acid concentrations of only 3.5 ppm. Only trace amounts of iron exist and the mean sulfate concentrations is 58 ppm. This minor source of AMD, of mainly deep mine origin, is the last direct source of AMD to the West Branch.

Abatement of AMD in the Cooks Run, Milligan Run, and Kettle Creek area will be difficult due to low alkaline reserves. Extensive surface restoration may only achieve 30 percent effectiveness and deep mine sealing will be difficult. Low flow augmentation using the Kettle Creek Dam and neutralization by treatment facilities could return utility to nearly all streams now affected. Only Cooks Run and Kettle Creek justify

AMD abatement expenditures. Estimates of abatement cost for both watershed areas is placed at $10.5 million initially and $400.00 annually.

Bald Eagle Creek

Bald Eagle Creek flows northeast along the northern edge of Bald Eagle Mountain to its confluence with the West Branch just west of Lock Haven. Bald Eagle Creek contributes about 130,000 ppd alkalinity (72) to the West Branch. Bald Eagle Creek receives one tributary stream significantly polluted by AMD. This tributary, Beech Creek, discharges an average of over 13,000 ppd acid to Bald Eagle Creek (18). Beech Creek drains approximately 170 square miles of northern Centre and southwestern Clinton Counties which are partially underlain by the southeastern edge of the Main Bituminous Coal Field. In 1970, four surface mining companies accounted for a production of about 0.25 million tons of coal. Economically recoverable coal seams exist in the area between Clarence Village and the abandoned town of Kato.

Normally, AMD entering Bald Eagle Creek from Beech Creek is neutralized by the high alkaline reserves of Bald Eagle Creek. In fact, all remaining acid in the West Branch of the Susquehanna River is neutralize shortly after its confluence with Bald Eagle Creek. It has abundant bass and muskellunge both above and below its confluence with Beech Creek. Little aquatic life exists in the Beech Creek Watershed except for a few tributaries in the mid to lower reaches. The Corps of Engineers is currently interested in expanding recreational potential of areas in the

Beech Creek Watershed.

Streams in the watershed have practically no alkalinity or buffering capacity. Some sandstones, shales and conglomerates contain high concentrations of acid-forming materials. Geologic studies conducted in the vicinity of the South Fork headwaters region of Beech Creek have shown that unmineable coal seams and small coal lenses, exposed during construction of Interstate 80, contain over 15 percent pyrite (41).

An intensive mine drainage study was conducted under the former Department of Mines and Mineral Industries' Project No. SL-111 (18). Selected findings are mentioned here. An estimated 14 percent or 23 square miles of the Beech Creek Watershed is underlain by seven major coal seams. From oldest to youngest they are the Mercer; Brookville; Clarion; Lower, Middle, and Upper Kittanning; and the Lower Freeport. An east-west oriented syncline, which controls exposure and orientation of the coal seams, is located in the vicinity of Clarence, Kato, and Orviston Villages and has its greatest depth near Clarence. The area near Clarence is underlain by all seams and has been extensively mined.

Mining was extensive in most areas on all seams except the Clarion and Brookville. Most deep mines were developed to the rise of the coal to facilitate natural gravity drainage. Some deep mined areas which required pumping have since become inundated. Three pools exist

in the watershed, one near Cherry Run Village, and the other two separated by a large barrier pillar in the Brookville seam. One extends along the synclinal trough to Sandy Run from Little Sandy Run. Of the 23 square miles of coal measures in the watershed, 33 percent or 8 square miles have been affected by 188 separate coal and clay strip mines. These mines,to varying degrees, allow infiltration or direct passage of precipitation to deep mine workings. Deep mine practices, open strip pits, and associated refuse are sources of significant amounts of AMD. Of the ninety-one deep mine entries in the watershed, only five provide direct access of surface waters to deep mine workings. A total of thirty-nine subsidence areas were found in the watershed, most of which are associated with the Brookville and three overlying seams. Two areas of stream infiltration were found along Cherry and Sandy Runs.

During a one-year sampling period (18), from Fall 1968 to Fall 1969, a total of 184 MD discharges were located in the sub-basins of North Fork, Beech Creek and Sandy Run. Others were found on the south side of Beech Creek between Kato Village and Logway Run, however, none were found downstream of the confluence of Twin Run and Beech Creek. Twenty-five of the 184 mine discharges are emanating from deep mine entryways predominantly from the Brookville and Lower Kittanning seams. An additional 16 MD discharges were located in apparent association with deep mines where AMD appeared to flow over underclays to the surface

as springs. This type of drainage is also quite common in the adjacent Moshannon Creek Watershed. Fifteen boreholes drilled to relieve pressure from deep mine pools, discharge AMD. A total of 168 discharges discharged MD originating from a combination of strip and deep mine workings . Of the thirty-three refuse areas, seventeen accounted for twenty-five discharges, although all areas probably create acid discharges during wet periods. One remaining source of acid drainage was located in the South Fork of Beech Creek. This comes from Interstate highway fill material that contains high concentrations of reactive pyrite.

Most of the AMD discharges are in a few areas within the watershed. Under average conditions, 88 percent (or 43,378 ppd) of Beech Creek's acid and 97 percent (or 3,156 ppd) of its iron emanates from the North Fork and Sandy Run sub-basins. Four other tributaries account for 4 percent of Beech Creek's flow, 9 percent of its acid and 2 percent of its iron. Tributaries conveying portions of this mine drainage are discussed below.

The South Fork at its mouth averages 26 ppm acid with pH's ranging from 3.8 to 4.7. Upstream the South Fork has concentrations of acid ranging from 63 to 164 ppm with pH's between 3.7 and 4.9. Iron concentrations range from 0.9 to 2.0 ppm. The North Fork of Beech Creek receives the greatest concentrations of AMD. Acid concentrations range from 65 to 370 ppm with pH's between 3.0 and 4.5. Iron

concentrations range from 1.7 to 35 ppm. Concentrations of mine drainage indicators at the mouth of the North Fork averaged 71 ppm acid, 172 ppm sulfate, and 3.1 ppm iron with an average pH of 3.7. Sandy Run and its tributaries are also of poor water quality, the most polluted being in the downstream reaches where acid and iron concentrations range from 114 to 542 ppm and 7.5 to 31.0 ppm respectively and pH ranged from 2.9 to 3.4. Logway Run is the only other tributary of Beech Creek which suffers extreme AMD degradation. At its mouth Logway Run's average acid concentration is 312 ppm and concentrations of iron range from 12 to 24 ppm. The average pH is 3.3 and a low of 2.9 was recorded.

Tributaries of generally good water quality are Big, Twin, Three Rock, Two Rock, and Council Runs and downstream reaches of Wolf Run. No MD discharges were found in the upper reaches of Wolf, Cherry, Monument, and Hayes Runs, which support observed minnow and trout life. The above tributaries discharge water of only slightly above the average background levels of mine drainage indicators.

The total affect of all sources of AMD on the Beech Creek Watershed was recorded near the mouth of Beech Creek 1 mile from its confluence with Bald Eagle Creek. At this point pH's ranged from 3.9 to 4.5 with an average of 4.2. Acid, sulfate, and iron concentrations varied from 26 to 70, 50 to 152, and 0.1 to 0.6 ppm respectively. Average

concentrations of acid, sulfate and iron were 44, 91, and 0.3 ppm respectively. Based on an average flow of 57 cfs, Beech Creek contributes an average 13,500 ppd acid to Bald Eagle Creek. Other MD loadings are 92 ppd iron and 28,000 ppd sulfate.

Abatement techniques for the Beech Creek area determined under Project SL-111 (18), were reviewed for their potential effectiveness in reducing or eliminating AMD. From a total of ten considered applicable, nine were preventive measures. The other technique considered was neutralization, oxidation, and settling for removal of the remaining AMD. An abatement plan was recommended which would eliminate AMD at 48 MD discharge points and reduce AMD at four MD discharges. Three separate collection and treatment systems were recommended for thirty MD discharges including three discharges reduced by preventive measures. Approximately 99 percent of the AMD reduction by treatment would be achieved by two of the three treatment plants. Treatment would be confined to the upper parts of the watershed which would benefit downstream areas. Of the total cost, 75 percent is recommended for preventive measures throughout the watershed and about 18 percent for collection facilities. Of the estimated 92 percent AMD reduction, 40 percent is to be eliminated by preventive measures. Preventive measures, for the most part, are: strip mine, stream channel, and

subsidence restoration; surface-water diversion; and deep mine inundation or outcrop sealing.

Preventive project costs are estimated at 16 million dollars initially, plus $300,000 annually. Treatment costs are estimated at $7.7 million initially plus $600,000 annually.

Beech Creek is anticipated to have a water quality which would support extensive biologic activity after implementation of the recommended abatement.

The DER has initiated a Quick Start AMD abatement project in the vicinity of the confluence of Panther Run and Beech Creek. Abatement will consist of regrading refuse, covering it with soil, planting, and the construction of surface water diversion ditches.

West Branch - Bald Eagle Creek to Mouth

The quality of the West Branch changes significantly in this reach, primarily in response to alkalinity brought to it by Bald Eagle Creek. Its 130,000 ppd alkaline load (72) enters the West Branch at mile 68 and contributes most of the alkalinity required to neutralize any remaining acid under normal flow conditions. Other major alkaline tributaries in the reach between miles 68 and 40 (Williamsport) include Pine, Larry's, Lycoming, and Loyalsock Creeks.

During unusual flow conditions caused by relatively excessive rainfall in the main bituminous coal fields, alkaline input by the above mentioned streams may not be sufficient to neutralize all the acid in the West Branch, and it can become acid to its mouth. These conditions prevail during heavy autumn rains when concentrations of AMD are flushed from the deep mines.

Pine Creek is affected by two isolated coal fields that are extensions of the main bituminous field. The northernmost field, which also affects the Tioga River Basin, is drained by Babb Creek and its tributaries. Babb Creek is initially affected by Wilson Creek. Wilson Creek is polluted primarily by deep mine discharges. A total of seven discharges, each yielding greater than 450 ppd acid (72) (three of these were in excess

of 1,000 ppd) were located in Wilson Creek. The largest source (with a flow of 0.9 cfs) enters the headwaters of Basswood Run, a tributary to Wilson Creek. Just south of the village of Antrim an old drift discharges 1,500 ppd acid (72) (flow of 1.8 cfs) to Wilson Creek. The last large source of AMD entering Wilson Creek discharges from a stripped-out drift. This drainage then disappears into the ground halfway down the mountain north-west of Antrim, and probably reappears as seepage to Wilson Creek. Wilson Creek has a flow of 9.2 cfs and discharges 4,300 ppd acid to Babb Creek with concentrations of acid, sulfate, and iron of 86, 109, and 2.4 ppm respectively.

Two miles downstream from the mouth of Wilson Creek, Stony Fork, a tributary to Babb Creek, is seriously affected by AMD. Stony Fork is only affected by AMD from Paint Run. This is a tributary that enters two miles from the mouth of Stony Creek. Two major discharges enter the north side of Paint Run. A discharge from an abandoned drift and a coal processing pond contribute 2,000 and 2,300 ppd acid to Paint Run respectively. Four miles of tributary and main stream are polluted in the Stony Fork Watershed.

Two miles farther downstream Babb Creek, with a pH of 4.75 discharges 1,500 ppd acid to Pine Creek. Pine Creek with a flow of over 300 cfs and a pH of 7.8, completely neutralizes all of the acid from

Babb Creek. Other concentrations of mine drainage indicators entering Pine Creek are not exceptionally high. Presently the DER (50) is conducting an AMD study under project SL-145 in the Bear Run Mine complex area of the Babb Creek Watershed.

The southernmost coal field in the Pine Creek Watershed is located near English Center in northwestern Lycoming County. An extensive AMD study was conducted in this area under the DER's Project SL-160 (16). Portions of the project's findings are reported here. A sampling program was conducted from July 1970 to June 1971 in both watersheds. Otter and English Run (at English Center), two tributaries of Little Pine Creek, are affected by AMD emanating from abandoned deep mines. Otter and English Runs have a combined drainage area of 50 square miles. At present several neutralization plants treat mine outfalls on Pine Run (a tributary of English Run), and Buckeye Run, (a tributary of Otter Run).

Three major coal seams, underlying the area between English and Otter Runs, have been mined. The "B" or Blossburg coal, low in sulfur and 4 to 5 feet thick has been deep mined most extensively (figure 4). The higher "C" or Cushing and "E" or Smut seams have also been mined. The coal seams lie in a northeast-southwest trending synclinal basin. At the mouth of English Run pH ranged from 4.8 to 6.6 and average

acid, sulfate, and iron concentrations are 12.0, 0.1, and 38.0 ppm respectively. English Run discharges 4,600 ppd acid to Little Pine Creek. Shingle Mill Branch, a tributary to English Run, has average concentrations of 16 ppm acid, 103 ppm sulfate, and 0.3 ppm iron. Pine Run is the only other tributary to English Run which is affected by AMD. It was in this stream that the effects of AMD pollution was first noticed. In 1958 this stream was removed from the Fish Commission's list of approved Brook Trout Stocking Streams. A local sportsman's organization, with the aid of the Department's contract SL-125, is using a limer to neutralize the Carson Mine outfall, the only major source of acid in Pine Run. During the sampling period an average pH of 4.72 was recorded at the mouth of Pine Run. Acid, iron, and sulfate concentrations averaged 3.3, 0.3, and 30 ppm respectively. Before the lime neutralization was used on the Carson Mine Outfall, concentrations of acid and sulfate were 53 and 50 ppm respectively, with a pH of 3.6. Farther upstream additional sources of AMD were found entering Pine Run which affect its full length.

During the sampling period from July 1970 to June 1971 a total of 304 samples were collected in the Otter Run Watershed. Otter Run discharges 3,500 ppd acid to Little Pine Creek. Concentrations of acid, sulfate, and iron are 6, 28 and 0.75 ppm respectively. Values of pH

recorded at the mouth of Otter Run ranged from 4.7 to 6.5 and averaged 5.55, indicating somewhat more acidic conditions that English Run which is, however, being treated. In the coal lands west of Buckeye Run, a tributary to Otter Run, the DER (50) undertook a mine sealing project which was completed in May 1971. This project (Thomas Mine) consisted of backfilling with local clays and covering with overburden. One year later the project appeared to be successful. Water quality samples below this recently completed project showed a considerable water quality improvement within a short period of time. A yearly high pH reading of 4.8 was recorded in addition to a pH increase from an average 4.06 to an average 4.52. In an area east of Buckeye Run a relatively large amount of AMD drains from strip mines. This water has pH's consistently below 4.0. Sulfates ranged from 190-560 ppm with acid concentrations ranging as high as 200 ppm. The 3 square mile Otter Run Watershed has 320 acres of strip mined lands.

One method which will control undesirable runoff in English and Otter Runs is the use of impoundments at selected localities. The U.S. Department of Agriculture through its Soil Conservation Service performed field surveys in both watersheds and selected impoundment areas. These sites will have the combined purpose of sediment control and low flow augmentation. Five sites were located in the English Run Watershed

which could be utilized to reduce sediment transport, concentrations of AMD, and augment stream flow as desired. The estimated cost of the five dams is $1.4 million. The location of four of the five dams is such that essentially all of English Run would benefit from their intended use. Three sites were located in the Otter Run Watershed which could reduce sediment and AMD loadings. All three dams are located in areas presently contributing most of the mine drainage entering Otter Run. The total estimated cost of the Otter Run dams is 1.1 million dollars.

Many of the commonly employed preventive measures appear to be applicable in solving English and Otter Runs AMD problems. Numerous mine seals were recommended under Project SL-160. The combined use of surface restoration, mine sealing and low-flow augmentation should aid in greatly reducing AMD loadings both in English and Otter Runs and their receiving stream, Little Pine Creek.

Full use of these preventive measures for the Babb Creek Watershed may not be possible. Current investigations in the adjacent Tioga River Basin area may aid in determining the applicability of abatement measures in the Babb Creek area. Estimated cost of abatement, which includes limited treatment is placed at $4 million and $25,000 annually for the Little Pine Creek and Babb Creek Watersheds.

Loyalsock Creek is the farthest downstream tributary of the

West Branch that drains an area underlain by coal. Loyalsock Creek's confluence with the West Branch is located about 4 miles east of the town of Williamsport. Loyalsock Creek is affected by (72, 27) an isolated small semi-anthracite coal deposit north of Loyalsock Creek near the town of Lopez. Presently Loyalsock Creek is of marginal water quality with regard to the Pennsylvania Fish Commission's (46) water quality requirements for a healthy fish population. This particular reach of affected stream extends from Lopez to Forksville where Loyalsock Creek's water quality is im-improved by alkalinity from Little Loyalsock Creek.

Loyalsock Creek is affected by AMD from two tunnels near the village of Lopez. They discharge a total of 6 cfs with a net acid load of 2,000 ppd (27). These discharges cause degradation of Loyalsock Creek as far west as Forksville due to the natural low alkaline reserves in this part of the watershed. Since all mining activities have ceased in the Loyalsock Creek area, mine sealing may be possible. Treatment would also be possible as an alternative and last resort. Estimated cost of abatement for the Loyalsock Creek Watershed is $800,000 initially and $75,000 annually if treatment is required. The DER (50) is currently initiating an AMD abatement study in the Loyalsock Creek area near Lopez under Project SL-188. Results of this study will add greatly to the solution of Loyalsock Creek's AMD problems and their cost estimates.

JUNIATA RIVER

The Juniata River Basin drains an area of approximately 3,400 square miles, nearly all of which is located in the Valley and Ridge Provin (figure 2). The ridges in the western part of the basin are steep and rugge while the eastern part is considerably more rolling in nature. The northwestern part of the Basin drains part of the eastern edge of the Appalachian Plateau Province. Extremes in elevation range from 340 feet at the confluence of the Susquehanna and Juniata Rivers above Harrisburg to 2,900 feet near Blue Knob, northwest of Altoona.

Forest covers approximately two-thirds of the watershed. The re mainder is devoted to farming restricted mostly to the lower, more fertile valleys. The coal measures underlie parts of Blair, Huntingdon, Bedord and Fulton Counties (Plate 1). The headwater areas of the Juniata River Basin drain into four major tributaries of the Juniata River. These head-water streams parallel one another and follow the northeast-southwest trending valleys. The Little Juniata River flows from Altoona northeast toward Tyrone. From Tyrone the Little Juniata cuts perpendicular througl valleys and ridges, flowing southeast toward its confluence with the Franks town Branch and forms the main stream of the Juniata River. The Juniata River continues flowing southeast to its confluence with the Raystown Branch. After an additional 12 miles the Juniata River receives it fourth

major tributary, Augwick Creek. Downstream from the confluence of Augwick Creek the Juniata River turns and flows northeast toward Lewistown, then meanders eastward toward the Susquehanna River. The Raystown Branch and Augwick Creek drain a small, 12 square mile, part of the Main Bituminous Coal Field in Blair County and the entire 81 square miles of the Broad Top Field located mainly in Huntingdon and Bedford Counties and a small part of Fulton County. The Broad Top Field is an isolated coal field with a maximum width and length of 8 and 12 miles respectively.

The Broad Top Field is a unique coal field having geologic characteristics of the Main Bituminous and Anthracite Fields. Structurally the Broad Top Field is steeply folded and has seams of coal which require the same mining techniques as the moderately high pitched seams of the Anthracite Region. The number and type of coal seams resemble the low volatile bituminous seams found to the west in Somerset and Cambria Counties. Twelve hundred feet of stratigraphic section contain a maximum of 12 coal seams. Major coal seams in the Broad Top Field are the Clarion, Lower and Middle Kittanning, Upper Freeport, Speer and Pittsburgh seams of the Allegheny and Conemaugh Groups (Figure 4).

A small part of the Main Bituminous Field is drained by the headwaters of the Little Juniata and the Frankstown Branch. All coals in

this area are ranked medium volatile bituminous and belong to the Allegheny Group.

Mining in the area dates back to the Revolutionary War when mining was done for more local usage. Commercial coal shipments were first made in 1853. Since then production increased to a peak of 2.7 million tons in (11) 1918. After World War I production dropped to approximately 1.6 million and remained relatively stable until shortly after World War II, in 1947, production increased to about 2.0 million tons. Since then production has decreased considerably. In 1964 total production within the Juniata River Basin was only 374,000 tons. In 1964 predictions were made that production would increase to 490,000 tons by 1970. Records (11) show that total production only reached 22,560 tons. Coal production almost ceased in all but Bedford County. Bedford County produced about 18,300 tons in 1970.

Deep mining was conducted mainly in the Clarion, Lower Kittanning and Upper Freeport seams and was somewhat more limited in other seams (17). Deep mining was conducted both above and below local surface drainage. Consequently, both gravity discharges and mine pool overflows contribute significant amounts of mine drainage. The lack of effective barrier pillars causes mine water to circulate over long distances. Mining below surface drainage necessitated the use of pumping. Since deep mining

ceased mine pools have developed and are numerous in the Coaldale area of the Raystown Branch. The last deep mine operations were conducted above mine pool elevations. Strip mining was conducted in all seams in the past. The last seam extensively stripped was the Pittsburgh. Inadequate restoration of past strip mines has affected about 5 percent of Juniata Coal measures (17). Deposits of refuse from past mining operations, based on available information, are not a major source of acid drainage.

Little Juniata River

The extreme headwaters area of Bell Gap Run has been affected by extensive strip mining which extends over into the Powell Run Watershed, a tributary to Clearfield Creek. Local rock structure in this area causes most of the drainage to flow northwest toward the Powell Run Watershed away from Bell Gap Run. Available information indicates that Bell Gap Run exhibits very little evidence of mine drainage indicators at its mouth. It contributes about 200 ppd alkalinity to the Little Juniata River. Under the DER's (68) project SL-153 approximately 130 acres of stripped land were reclaimed. The Bell Gap Run is presently a source of public water for the town of Bellwood.

Frankstown Branch

The major recipient of AMD is the Beaver Dam Branch, a tributary to the Frankstown Branch of the Juniata River just east of Hollidaysburg. Of the three major tributaries to the Beaver Dam Branch, (1) Burgoon Run, (2) Sugar Run, and (3) Blair Gap Run, only the first two tributaries are appreciably affected by AMD.

Beaver Dam Branch upstream from Burgoon Run is highly alkaline, averaging 2100 ppd, even during low flows of about 3.0 cfs. Burgoon Run at its mouth has pH's which are as low as 2.8. Sulfate and iron concentrations are about 389 and 17 ppm respectively. Burgoon Run contributes 8,600 ppd acid to Beaver Dam Branch, severely degrading its water quality. Downstream from Burgoon Run, Beaver Dam Branch has an acid load of 5,300 ppd with a pH of 3.9. Burgoon Run has one single large source of AMD, Kittanning Run,which receives 16,000 ppd acid discharge from a deep mine in its headwaters. Kittanning Run's confluence with Burgoon Run is located above the Kittanning Reservoir in the famous Horseshoe Curve. Acid concentrations at the mouth of Kittanning Run ranges from 370 ppm to 400 ppm. An AMD treatment plant with a capacity of 7.5 mg/d was constructed by the DER (68) for the combined purpose of treating this AMD and further upgrading treatment of required amounts of water for the city of Altoona. Initial costs

were paid by the DER and all other costs will be paid by Altoona.

Sugar Run, at its mouth, has mean acid sulfate, and iron concentrations of 31, 187, and 0.21 ppm respectively. A flow of 3.8 cfs contributes about 630 ppd acid to Beaver Dam Branch which upgrades its water quality in the absence of upstream treatment. Sugar Run has one major source of AMD, a discharge of about 5,200 ppd acid from an abandoned deep mine 1 mile southeast of Gallitzin. Currently this water is being diverted around a reservoir. Treatment of this AMD was considered as an alternative supplementary source of water for Altoona.

Blair Gap Run contributes an abundance of alkalinity to Beaver Dam Branch. Downstream from the confluence of Blair Gap Run and Beaver Dam Branch the stream has a pH of 6.3 and net alkaline load of 5,000 ppd.

Raystown Branch

Acid mine drainage is conveyed to the Raystown Branch of the Juniata River by Sandy Run, Six Mile Run, Shoups Run, and Great Trough Creek. All tributaries except Great Trough Creek have drainage areas which lie totally within extensively mined sections of the Broadtop Fields. Under the FWPCA's contract no. WA66-21 (17), Six Mile Run, draining the Coaldale area, was the object of an AMD feasibility study. Portions of

those findings are reported here in addition to more recent information. The largest single source of AMD to Six Mile Run is an artesian flow, associated with the Clarion and Lower Kittanning Seams. This flow discharges an average of 2,000 ppd acid. The second largest contributor of mine drainage to Six Mile Run is a discharge from an Upper Freeport deep mine averaging 1,300 ppd acid. These two discharges contribute 41 percent of the 7,900 ppd acid entering Six Mile Run. Recommended preventive abatement measures including strip mine restoration, reconstruction of stream channels, and deep mine sealing, are estimated to cost $1.0 million and will reduce 1,400 ppd acid for 18 percent abatement. The remainder of the AMD would be treated for nearly 100 percent abatement. Cost of treatment, utilizing neutralization techniques, for the remaining acid is estimated at 0.5 million initially and $140,000 annually. Total abatement costs are estimated at 1.5 million dollars initially and $140,000 annually. If reductions of AMD indicators are desired only for the removal of AMD entering the Raystown Branch, costs could be reduced to 0.67 million initially and $40,000 annually.

Shoup Run contributes about 3,200 ppd acidity to the Raystown Branch. Two deep mine discharges contribute about 90 percent of the acid or 6,300 ppd to Shoup Run. The largest single source of AMD is a mine relief borehole about 1 mile west of Broad Top City which discharges

about 5,500 ppd acid with a flow of 9.5 cfs (72). Initial and annual abatement costs are estimated to be equivalent to the cost for Six Mile Run.

Great Trough Creek's headwaters lie west and adjacent to the headwaters of Shoup Run, Six Mile Run and Sandy Run. Despite extensive deep and strip mining in Great Trough Creek, this watershed has relatively good water quality. The large deep mine discharge in Shoup Run, mentioned above, drains a large part of the Great Trough Creek Watershed which accounts largely for its relatively good water quality.

The south branch of Sandy Run receives about 1,000 ppd acid, mainly from deep mine pools and local gravity discharges. Available information indicates that Sandy Run is not acid at its mouth and that total abatement of acid mine drainage will clean up only a small reach of Sandy Run. Abatement costs are estimated at 0.3 million dollars.

Augwick Creek

A small percentage of the Broad Top coal fields lies in the Augwick Creek Watershed. Roaring Run, a tributary to Sideling Hill Creek, conveys about 2,200 ppd acid (27) to Sideling Hill Creek which is able to overcome this acid and have an alkaline discharge to Augwick Creek. Total abatement of AMD, which emanates from one source is estimated to cost $100,000 initially and $40,000 annually. Abatement of this AMD will re-

claim several miles of otherwise unpolluted streams.

Costs for nearly total abatement of remaining AMD for the Frankstown Branch, Raystown Branch, and Augwick Creek areas are estimated at $3.1 million initially and $320,000 annually. These costs would be substantially higher in the absence of the DER's AMD treatment plant which is abating a significant amount of pollution entering a tributary of the Little Juniata River.

The DER has given attention to other areas within the Juniata River Basin. Currently under the DER's project SL-184-1 an evaluation of the potential effectiveness of mine sealing is being made for the Coaldale area on Six Mile Run. Preventive abatement measures have also been planned for the Frankstown Branch in Juniata Township.

TIOGA RIVER BASIN

The Tioga River and its tributaries dissect and drain a 1,391 square mile area of the Allegheny Plateau Province. (Figure 2) Six hundred ninety miles of this province lie within Pennsylvania. The extreme headwaters of the river are located in Armenia Township of western Bradford County. From this area the river flows two miles southwesterly to the Tioga-Bradford County line continuing southwest, and eventually turning north toward the town of Blossburg, 13 stream miles from the Tioga-Bradford County line. From Blossburg the river flows north into New York State to its confluence with the Chemung River. This river flows southeast to join the North Branch of the Susquehanna River just across the Pennsylvania border.

Three miles southeast of Blossburg the Tioga River dissects the Pottsville and overlying Allegheny Group coal bearing strata. These isolated rock units belong to a northeast extension of the main bituminous coal field, which was eroded away in adjoining structurally higher areas. The low lying coal basin rises toward its eroded edge to the northeast paralleling the watershed boundary of Fall Brook, a tributary to the Tioga River. The axis of the Basin plunges toward the southwest and is in close proximity to Coal Creek. The southern erosional edge of the coal basin dips slightly steeper to the northwest than the northern edge dips to the southeast,

just south of East Creek. The coal basin has nine major coal seams, the lowest being the Brookville and the highest the Upper Freeport (figure 4). The coal seams are separated by shales and sandstones. Low-lying areas contain glacially derived materials. Acid-forming materials are found in association with all coal seams and are particularly abundant in the Brookville, Lower Kittanning, and Lower Freeport seams.

Numerous entryways or drifts were driven into the outcroppings of these seams to gain access to the coal. The location of these drifts provides gravity discharge of mine water which percolates downward from overlying perches water tables. Concentrations of dissolved salts and acid emanating from these entries still remain high although nearly a century of time has lapsed since deep mining began in the Tioga watershed.

Mining operations in the Tioga River watershed date back to the 1840's and have been the mainstay of the economy for many years. A maximum production of 1.4 million tons was reached during the Civil War years and then declined to about 0.4 million tons (11) in 1964, 100 years later. Prior to World War II nearly all mining was subsurface. Since then deep mining has declined and ceased in the late 1960's. During this long period of deep mining numerous entryways were driven to provide access to the coal, ventilation, haulage, and gravity drainage for the mines. Underground extraction of coal has caused extensive fissuring of the overburden and subsequent subsidence. Surface runoff is greatly reduced due to both deep and past strip mining practices.

Strip mining was last performed on the Middle and Upper Kittanning as well as the Lower and Upper Freeport seams. Past strip mining has affected an estimated 640 acres of land in the Morris Run, Coal and Bear Creek watersheds. An additional 348 acres has been disturbed by more recent strip mining to total about 12 percent of the area. In 1970 the Jones and Brague Coal Company of Blossburg, Pennsylvania was the only active operator in the Tioga River basin and is one of the larger strip mine operators in Pennsylvania (4). In 1970, the company's production was 747,946 tons, the total production for Tioga County. During this year the company had seven separate operations employing a total of 112 men, 17 of these worked at the tipple and cleaning plant.

Total remaining coal reserves in Tioga County were estimated at nearly 120 million tons in 1970. The coal basin near Blossburg is estimated to have 41 million tons of reserves with about 40 percent being economically recoverable (14). Present production rates could deplete this recoverable reserve within 10 to 12 years.

The tributaries of the Tioga River which are severely degraded by AMD are Morris Run, Coal Creek, and Bear Creek. AMD from these tributaries causes the Tioga River to run continually acid for 17 miles, from Morris Run to Mill Creek just south of Tioga. During low flow the

Tioga River may run acid from Morris Run to the New York State border, an additional 10 miles. Some acid mine drainage may be contributed by Johnson Creek, however it has enough natural alkalinity in its headwaters to neutralize the AMD.

Recent water quality analyses of the Tioga River upstream from Morris Run indicates that except for during low flow conditions the river remains alkaline. Values of pH range from 6.0 to 7.5, accompanied by only trace amounts of acid mine drainage indicators. During both abnormally high and low flows the river receives acidity not completely neutralized by natural alkaline reserves.

Morris Run at its mouth contributes large amounts of acid mine drainage to the Tioga River. Recent data indicates that pH ranges from 2.5 to 3.5 with a mean value of 3.1 (4). Net acidity ranges from 230 to 1033 ppm with a mean of 639 ppm. Other acid mine drainage indicators vary from 284 to 3286 ppm sulfate, 16.0 to 86.3 ppm iron, and 15.4 to 54.5 ppm manganese. The average acid load of Morris Run at the mouth is 17,700 ppd. There are numerous discharges of AMD within the Morris Run Watershed. However, only two discharges contribute significant amounts of AMD. A gravity flow from a drift in the Lower Kittanning seam augmented by surface infiltration has an average discharge of 2.3 cfs and an acid load of 4,200 ppd. The second discharge,

of similar origin, has an average flow of 1.1 cfs with an acid load of 13,440 ppd. (4). These two discharges alone equal the acid load of Morris Run at its mouth.

Coal Creek, being located along the Basin's synclinal axis, receives drainage from an effectively larger area underlain by coal than either Bear Creek or Morris Run. Water infiltrating the surface travels long distances and consequently has a long contact time with an abundance of acid-forming materials. Due to structural controls on ground water movement along with deep mining practices, Coal Creek has the highest average flow per square mile of surface drainage area along this reach of the Tioga River. During low flow periods Coal Creek contributes 70 percent of all the acid mine drainage entering the Tioga River. Coal Creek along with Morris Run, normally contribute 90 percent of all acid mine drainage entering the River. Coal Creek has one major and exceedingly large acid mine drainage discharge. A gravity flow from a partially caved drift in the Lower Kittanning seam has an average discharge of 8.0 cfs with an average acid load of 30,800 ppd (4). At its mouth, Coal Creek has a pH range of 2.7 to 3.4 with an average value of 2.9. Net acidity ranges from 395 to 1,146 ppm with an average of 715 ppm. Sulfate concentrations range from 639 to 2,816 ppm with a mean concentration of 1,255 ppm. Iron and manganese concentrations range from 98 to 497 ppm and 10.8 to 26.5 ppm respectively. Coal Creek at its mouth contributes an average of

21,000 ppd acid (4) to the Tioga River.

The mouth of Johnson Creek is slightly acid (4). However, sulfate concentrations are sufficiently high to suggest acid mine drainage is entering the stream. Iron and manganese concentrations are very low and pH varies from 6.0 to 6.8. Two outfalls, having a combined total of 300 ppd acid, discharge to Johnson Creek.

Bear Creek is the only stream north of Coal Creek contributing acid mine drainage to the Tioga River. Recent water quality information indicates that Bear Creek, at its mouth, has values of pH which are consistently low. The range is very narrow, from 2.8 to 3.1, with a mean value of 3.0. Net acidity ranges normally from 650 to 210 ppm with a mean of 516 ppm. Sulfate concentrations range from 428 to 905 ppm with a mean of 530 ppm. Iron and manganese concentrations range from 11.0 to 46.0 ppm and 6.8 to 16.0 ppm respectively. Mean concentrations of iron and manganese are 20.0 and 9.3 ppm respectively. The mean acid load of Bear Creek, at the mouth, is 3,750 ppd.

When the flow of the Tioga River exceeds 700 cfs below Mill Creek sufficient alkalinity is introduced to offset acidity from the above mentioned acid tributaries. During normal and low flows, which occurred 90 percent of the time sampled, the Tioga River runs acid and may have pH's as low as 4.6. Below Crooked Creek the Tioga River flow must run below 50 cfs before the stream has a net acidity.

Abatement costs are estimated at 2.0 million dollars for extensive surface restoration. Follow-up treatment measures are estimated at 2.2 million initially and 440,000 annually for a total initial cost of 4.2 million dollars. Justification of abatement cost in the Tioga River Basin will be derived from construction of the Tioga-Hammond Lakes project for flood control, water quality, and recreation for an estimated 500,000 persons annually (4). The project will consist of one dam being built on Crooked Creek and another on the Tioga River, each being located about one mile up stream from their confluence. The lakes that form behind the dams will be joined by a channel excavated through the ridge separating the two valleys and a stationary spillway at the Hammond Dam site will serve both lakes. If sufficient acid mine drainage can be abated, maintenance of the $1.125 million physical barrier to separate Tioga Lake from Hammond Lake will not be required, due to AMD damages. Since benefits will be realized primarily by residents of New York, and Pennsylvania, Federal participation in an abatement program should be considered. In addition, 30 miles of stream will be returned to recreational use along with restoring utility to the reclaimed land.

Currently the DER (50) Project SL 136 is studying the effectiveness of strip mine reclamation of different types. This work is partially supported by the EPA. Project SL 136-1 is to provide the acid load reduction required to maintain an alkaline pool in the Tioga-Hammond Lake under stipulated

flow conditions. Abatement work in this area will receive a very high priority due to both Federal and State interest.

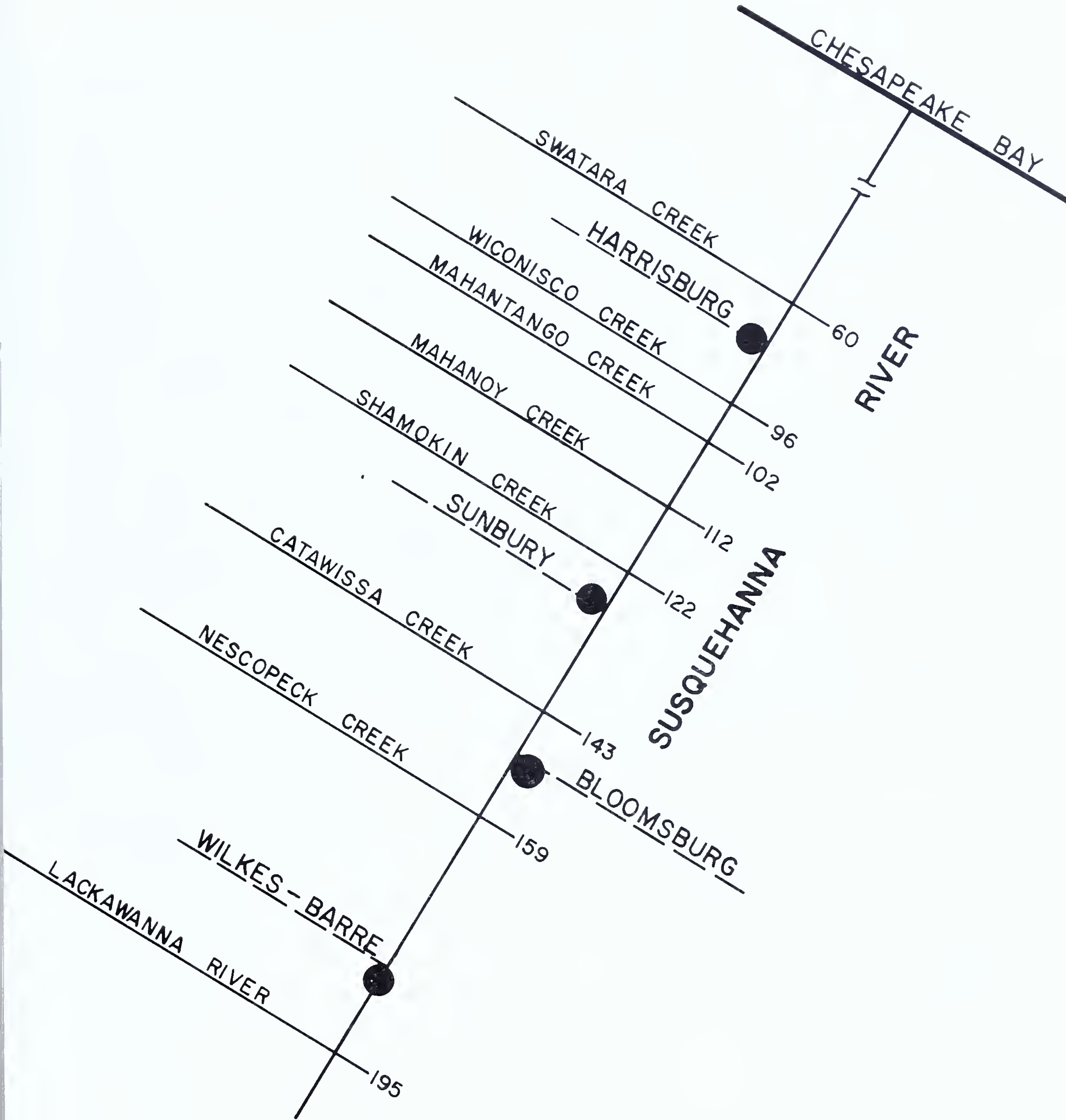
SUB-BASIN DISCUSSIONS ANTHRACITE REGION

The Anthracite Region is divided into four individual coal fields all of which lie in the Valley and Ridge Province of the Appalachian Highlands. The coal deposits occur in nearly U-shaped basins in and between ridges which trend northeast to southwest. The North Branch of the Susquehanna River enters the Northern Anthracite Coal Field between Scranton and Wilkes-Barre and then flows southwest leaving the Northern Field near Nanticoke. The Lackawanna River, which has its confluence with the North Branch of the Susquehanna near Pittston, is the largest tributary receiving AMD from the Northern Anthracite Field. The North Branch of the Susquehanna River then flows parallel to the Northern Field and passes through its southwestern tip, and remains outside of the coal measures to its mouth. The North Branch of the Susquehanna receives AMD from two major tributaries Nescopeck Creek and Catawissa Creek, which have their headwaters in the Eastern Middle Coal Field. Just north of Sunbury, the North and West Branches of the Susquehanna join to form the main stem of the Susquehanna River, which flows generally southward past the two southernmost coal fields. South of Sunbury the Susquehanna River receives discharges of MD from Shamokin and Mahanoy Creeks. These drain a large part of the Western Middle Field. The headwaters of three remaining tributaries of the Susquehanna, Mahantango, Wiconisco.

and Swatara Creeks, receive acid mine drainage from the Southern Coal Field. The four coal fields--Northern, Eastern Middle, Western Middle, and Southern--underlie 176, 33, 108, and 80 square miles of the Susquehanna River Basin respectively.

Major tributaries draining the Anthracite Region are tabulated below and shown schematically on figure 5.

Tributary Name	Drainage Area (square miles)	Mile Point of Confluence
Lackawanna River	346	195
Nescopeck Creek	172	159
Catawissa Creek	155	143
Shamokin Creek	138	122
Mahanoy Creek	155	112
Mahantango Creek	164	102
Wiconisco Creek	116	96
Swatara Creek	567	60



MAJOR TRIBUTARIES TO THE MAIN AND NORTH BRANCH SUSQUEHANNA RIVER

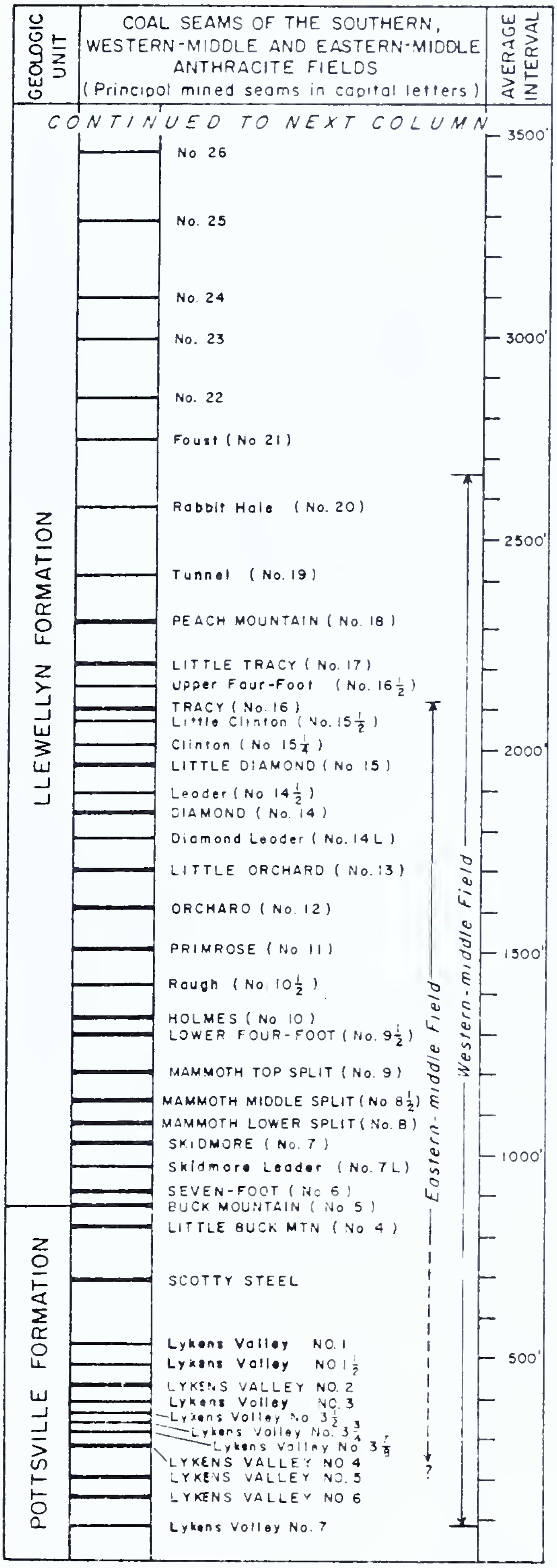
SCHEMATIC DIAGRAM OF STREAMS AFFECTED BY MINE DRAINAGE POLLUTION

FIGURE 5

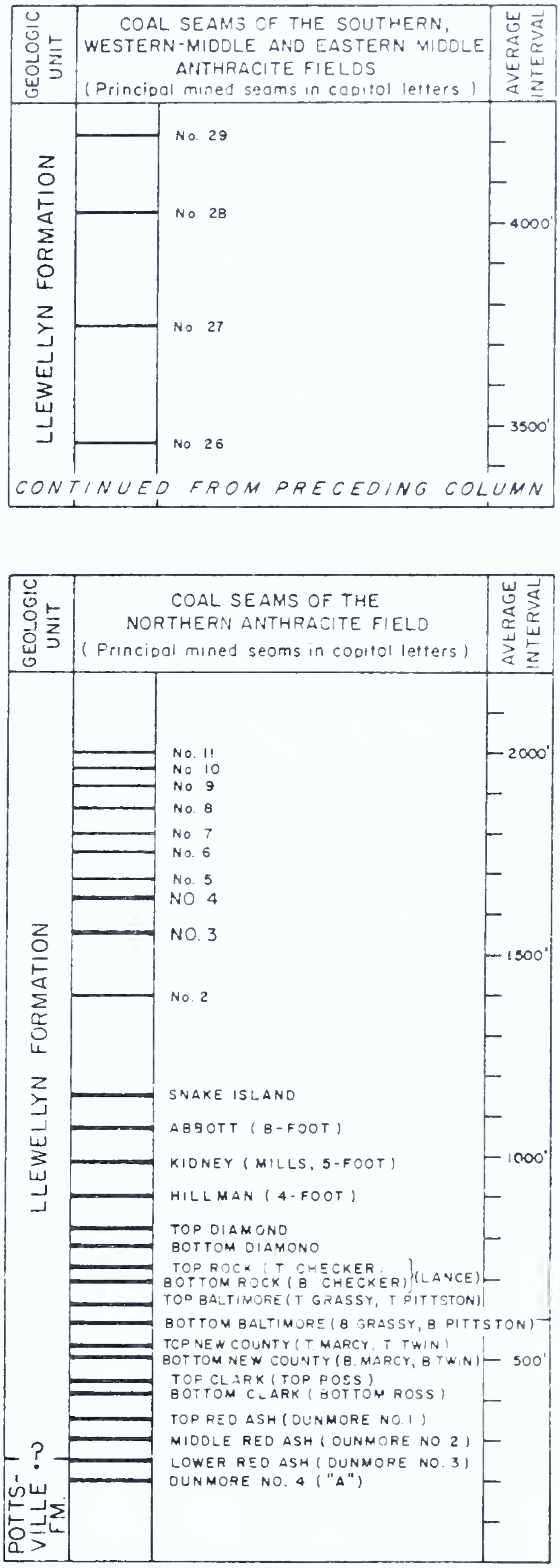
Rock units which immediately underlie the coal measures were deposited over 300 million years ago, during the Mississippian period. The overlying coal bearing units were deposited during the Pennsylvanian Period. Most coal seams mined are in the Llewellyn (post-Pottsville) Formation with fewer seams being mined in the underlying Pottsville Formation (figure 6). The Llewellyn Formation is usually mapped as the Allegheny Group in the Western Bituminous Coal Fields.

In the Anthracite Region the coal seams lie almost entirely in synclines (structural lows) where they were protected from erosion by the resistance of the underlying Pottsville conglomerate (Millstone Grit). Some of the synclines are of great depth - about 6,000 feet in the Southern Coal Field, which dips more steeply due to tight downfolding. Mining at such depths has never been accomplished and is part of the reason the Southern Field has such great coal reserves (14).

The Northern Coal Field emcompasses the trade region of Carbondale, Scranton, Pittston, Wilkes-Barre, Plymouth, Kingston, and Nanticoke. The Northern Field, underlying the Lackawanna - Wyoming Valleys, has coal deposited in a curved canoe-shaped syncline with a flat bottom and steep sides outcropping along the mountain ridges (Plate 1). The coal measures reach a maximum depth of 2,100 feet (14) (in the Wyoming Basin) and contain 18 workable seams. A structural saddle (high) near Old Forge, Pennsylvania, divides the Lackawanna and Wyoming Coal Basins. In the Northern Field,



Coal seams of the Southern, Western Middle and Eastern Middle Anthracite Coal Fields.



Coal seams of the Northern Anthracite Coal Field.

Adapted from 1973 Keystone Coal Industry Manual

GENERALIZED STRATIGRAPHIC COLUMN ANTHRACITE REGION

FIGURE 6

the lowest workable beds are the three Red Ash or Dunmore beds. Above the Dunmore beds lie the Ross or Clark seam and the Twin beds, followed by the Baltimore, Pittston, Fourteen-foot, Big Bed, or Grassy Island Bed, the nomenclature depending upon the Colliery that mined it. In the more southern fields, those seams are known as the splits of the Mammoth bed. Above this seam are the Rock, Diamond, Hillman or Olyphant No. 1, and Kidney followed by the highest seams--the Abbott and Snake Island Beds. Orientation and depth of coal seams in the Northern Field necessitated the use of shafts or slopes to gain access to the coal. Currently only one active deep mine exists in the Northern Field. In 1970 there was no deep mine production from the Lackawanna Coal Basin (12). Strip and bank mined production totaled 0.4 million tons. In the Wyoming Coal Basin deep, strip, and bank mined production was 0.57, 1.33, and 0.85 million tons respectively for a total production of 2.7 million tons (12). As of 1970, total remaining reserves in Northern Field was estimated at about 740 million tons (14). The Northern Field in Susquehanna and Wayne Counties has about 10.6 million tons of total reserves.

The Eastern Middle Field contains numerous long narrow coal basins that trend east and west. The underlying Pottsville conglomerate contains a few coal deposits. Most mined portions of coal deposits, contained within the mountain ridges, lie above natural drainage channels and are gravity drained by tunnels driven for that purpose only. The Jeddo

Tunnel to Little Nescopeck and the Audenreid Tunnel to Catawissa Creek both drain significant amounts of mine water from the Eastern-Middle Field. Numerous other entryways provide drainage from small parts of mine pools. The Eastern Middle Field contains the Green Mountain, Black Creek, Hazleton, Beaver Meadow, and Panther Creek districts which make up the Lehigh trade region.

In the Eastern Middle Field the Mammoth Bed, of about 60 feet in thickness, is the highest bed of major importance to the mining industry, particularly to strip operators. Other notable seams mined in the Eastern Middle Field are (lowest to highest), Buck Mountain, Holmes, Primrose, Orchard, Diamond, and Tracy. The seams of the Eastern Middle Field are contained within 2,000 feet of stratigraphic section (14).

The Western Middle Field encompasses the East Mahanoy, West Mahanoy, Shenandoah, and Shamokin trade region. Between the Shenandoah and Mahanoy coal basins lower coal seams, containing the Mammoth Bed, are folded over, doubling some of the coals in thickness. Most coal basins in this field, like the Shenandoah and Mahanoy Basins are almost totally beneath natural drainage channels. Consequently, mine pool overflows account for most of the acid mine drainage discharging in the area. All coal deposits in the Western Middle Field are contained

in about 2,500 of stratigraphic section (14). Coal seams are found pitching very steeply in some areas and nearly flat-lying in other areas. The Western Middle Field contains the same major coal seams found in the adjacent Eastern Middle Field. In addition to these seams several Lykens Valley seams are also present below the Buck Mountain vein.

The Southern Field, the largest of the four coal fields, only has 80 of its 200 square miles in the Susquehanna River Basin. This Field is extremely long, extending from the Lehigh River Valley westward almost to the Susquehanna River. Coal seams pitch or dip very steeply to depths of nearly 6,000 feet (14). Major parts of the coal basin in the Southern Field occupy positions both above and below natural drainage channels. Consequently, acid mine drainage emanates from both mine pool overflows and water level tunnels. All coal seams in the Southern Field are contained within 2,200 feet of stratigraphic section (14). There are approximately 26 coal veins mined in the Southern Field. The lowest vein commonly mined is the Lykens Valley No. 6 vein and the highest vein is the Peach Mountain vein.

Total estimated coal reserves as of January 1970, for the Eastern Middle, Western Middle and Southern Fields, are about 15 billion short tons (14). Reserves for all anthracite fields are estimated at about 16.4 billion

short tons. Recoverable anthracite reserves over 24 inches thick, are estimated at 8 billion short tons (14).

Coal mining operations were present in nearly all of the anthracite fields by the early 1800's. In 1870, total production by deep mine methods alone was about 14 million tons. By the turn of the century, there was a four-fold increase in total production which was still primarily by deep mine methods. During World War I total production reached a high of 100 million tons (10) of which 6.4 million was recovered using washery methods. After World War I total production decreased rapidly until about 1930. During this time, strip mining operations were small and were usually conducted by Collieries stripping their own outcroppings with small equipment. Strip mine production before 1930 was probably less than 2 million tons per year. After 1930 total production remained stable near 55 million tons up to 1948(10). During this time strip mining production increased from about 3 million to a high of nearly 11 million tons in 1944(10). Since this time strip mine production has gradually decreased. Deep mine production has also decreased since 1948. The DER's Annual Report (12) for 1971 lists total production in the Anthracite Region for 1960 at 9.25 million tons. Estimates indicate production for 1971 should fall about 10 percent below the previous year. In 1971, deep, bank, and strip mined production was estimated at about

1.24, 4.6, and 2.5 million tons (12) respectively. Declines in anthracite production are attributed more to economics than to lack of coal.

Lackawanna River

The Lackawanna River drains an area of 346 square miles. Most of this lies in Lackawanna County, and small parts of Wayne and Susquehanna Counties. Lackawanna County usually receives 41 to 48 inches of precipitation annually (23). Of this amount 20 to 24 inches evaporates or is transpired, 8 inches is overland runoff, and the remaining 13 to 14 inches is infiltration. Since the 1960's, a decrease in deep mining activities has had a significant affect on water quality of the Lackawanna River. Declines in the demand for anthracite has resulted in the abandonment of many deep mine operations and consequently, cessation of pumping. This resulted in the eventual development of extensive deep mine pools. As deep mines became inundated by rising water levels, a reduction of substantial amounts of ground water recharge effected. Since 1961, deep mine pool overflows discharge less ppd acid than was formerly pumped. This has caused an increase in stream alkalinity in the Upper Lackawanna. The Lackawanna River traverses the Valley with a gradient of about 14 feet per mile (23). These mine pools underlying the River have a gradient of about 4 feet per mile explaining the increase of mine overflows nearer the mouth of the

Lackawanna River. Presently there are no active deep mines in the Lackawanna Valley.

The Lackawanna River enters the Northern Anthracite Field about one mile north of Forest City (Plate 1). At this point, below the Stillwater Dam, The River is alkaline with an average pH of 6.8. The first major tributary to the Lackawanna, Brace Brook, introduces no significant amounts of AMD to the River. Other tributaries upstream from the first mine outfall, the Browndale, contribute little acidity to the Lackawanna River. After relatively dry periods the Browndale Outfall, 1 mile southeast of Forest City, discharges about 100 ppd acid (26). Discharges of 2 to 5 ppd acid and somewhat higher than normal amounts of sulfate are more common. The Lackawanna River, below the Browndale Outfall is alkaline with pH's averaging 6.3. One half mile downstream from the Browndale Outfall, the Vandling Outfall discharges an average 166 ppd acid into the Lackawanna River. Acid, sulfate, and iron concentrations average 10, 0.4, and 98 ppm respectively (26). Values of pH range from 4.2 to 5.0. About one mile farther downstream the Grey Slope Outfall discharges an average 45 ppd acid directly to the River (26). Other mine drainage indicators are similar to the Vandling Outfall. Downstream from the Grey Slope Outfall, the Lackawanna River begins to show slight increases of AMD indicators but still retains its alkalinity with pH's

ranging from 6.0 to 6.7. Approximately one mile downstream from the Beaver Outfall, near Carbondale, the Lackawanna River receives leachate that turns the Lackawanna River weakly acid. This source is seepage from the Northwest Dump seepage, composed of mine and breaker refuse with a silt pond, which turns all downward percolating water acid. The Northwest Dump contributes an average 177 ppd acid to the River along with other considerable amounts of AMD indicators. River water quality above the dump is alkaline, with mean alkaline and sulfate concentrations of 9 and 31 ppm respectively (26). Below the dump, the River has net mean acidity of 6 ppm and a mean sulfate concentration of 110 ppm. Only 600 feet downstream from the dump an Artesian well discharge contributes alkalinity to the Lackawanna River, enabling it to regain the same water quality it had just upstream from the Northwest Dump. Downstream from the well and above Wilson Creek the Lackawanna River water quality remains essentially unchanged. Wilson Creek, a tributary to the Lackawanna River just north of Carbondale, has three significant sources of mine drainage: (1) Upper Wilson Outfall, (2) Lower Wilson Outfall, (3) Lower Simpson Outfall. All of these outfalls are alkaline and possess equivalent concentrations of mine drainage indicators. Average flows are 0.74, 1.54, and 3.76 cfs respectively (26). The average combined total loading of mine drainage indicators for the

three outfalls are 388 ppd alkalinity, 18 ppd iron, and 7,155 ppd sulfate. Wilson Creek contributes an average of 361 ppd alkalinity, 13 ppd iron, and 7,566 ppd sulfate to the Lackawanna River. Below Wilson Creek the Lackawanna River has an average net alkalinity of 8 ppm, and an average iron and sulfate concentration of 0.3 and 85 ppm respectively.

The net effect all mine drainage discharges have on this 8 mile reach of the Lackawanna River has produced a decrease of 17 ppm alkalinity, and an increase of 62 ppm sulfate and 0.1 ppm iron. Most of the mine water discharging in this Upper Lackawanna Watershed emanates from the Lower Simpson Outfall. Mine water which does not discharge here is believed to flow over a small anticline and discharge, in part, from the Jermyn Outfall just south of the town of Jermyn. Available information indicates that the Jermyn Outfall discharges from 4,000 to 14,000 ppd acid (70) with a six-year average of 9,000 ppd acid and an average flow of 7.8 cfs. Acid, sulfate and iron concentrations range from 76 to 108, 141 to 280, and 5.6 to 28 ppm respectively. Mean concentrations of acid, sulfate and iron (total) are 133, 238, and 13.4 ppm respectively. About 3.5 miles farther downstream the mouth of the Lackawanna River receives additional AMD from the Peckville discharge. Data indicates that from the year 1963 to 1967 flows and associated AMD loadings were considerably less than in recent time. Since

1967, AMD loadings increased by one order of magnitude. Data for the past five years indicates an average discharge of 3,000 ppd acid (70). Larger flows are accompanied by only slight decreases in sulfate ppm relative to data after 1967. Immediately upstream from the Peckville discharge, the Danna and Waddell Outfalls, which were once active, no longer contribute AMD to the Lackawanna River.

Approximately eighteen miles farther downstream the Lackawanna River receives an AMD discharge from one of the largest single sources of mine drainage in the Anthracite Field, the Old Forge gravity discharge. Two miles farther downstream, and associated with Old Forge, the River receives another major discharge of AMD from the Duryea gravity outfall. When mine pools first broke through the surface of low-lying areas the Duryea Outfall was the largest source of AMD in the Anthracite Field. Shortly thereafter, the Old Forge Borehole was drilled to stabilize mine pool levels. Water quality information for the Duryea Outfall indicates an overall consistent decrease in acid concentrations. In 1962, shortly after mine waters broke to the surface acid concentrations decreased to 355, 269, 163, 214, 142, and 124 ppm from 1963 to 1968. These decreases in average acid ppm have also been accompanied by an average decrease of 25 percent in flow. This information indicates that partial depletion or exclusion of necessary reactants has occurred.

Since 1968, average acid concentrations have remained practically

unchanged (70). Values of pH have increased from an average 5.2 in 1963 to 5.9 in 1972. Sulfate concentrations, the most stable indicator of AMD activity, have also decreased significantly since 1962. Average sulfate concentrations have decreased from 2,900 to 900 ppm in the following ten years (70). Since tropical storm Agnes, water quality information for a four consecutive month period, indicated higher average concentrations of acid and sulfate similar to mine water emanating in 1966. The most recent water quality information indicates an improvement or trend toward lower concentrations of mine drainage indicators. This information indicates that the Duryea discharge with an average flow of 37 cfs is discharging 33,100 ppd acid to the Lackawanna River (70).

The quality of the Old Forge Borehole discharge is very similar to the Duryea's, indicating a common mine pool association. Chemical analysis of Old Forge and Duryea water samples, for the same time period, indicate practically equivalent concentrations of acid, sulfate, iron, and manganese. In 1971, information available indicated that Old Forge was discharging an average 54,100 ppd acid with an average flow of 83.7 cfs. Old Forge has a greater average flow than Duryea. For example, in 1970 the average flow for Old Forge and Duryea was 67 and 42 cfs respectively. The combined average discharge of both outfalls is about 90,000 ppd acid (70).

Analysis of data (70) indicates that since 1968 the combined outfalls

have undergone an approximate 32 percent reduction in acidity while maintaining a nearly constant flow. Recent data (70) indicates that Old Forge and Duryea have an average combined discharge of about 45,000 ppd iron. This causes severe water quality degradation in the Lackawanna River. The Lackawanna River between Old Forge and the Duryea Outfalls has average concentrations of 17 ppm acid, 12 ppm total iron, 206 ppm sulfate and 1 ppm ferrous iron. Below the Duryea Outfall the Lackawanna River has mean concentrations of 26 ppm acid, 10 ppm total iron, 285 ppm sulfate, and 0.71 ppm ferrous iron (75). Abatement of high concentrations of iron will be required to return affected waters to any beneficial use.

The Lackawanna Valley has a minimum of 2,150 acres of stripped land, requiring nearly 110 million cubic yards of original countour backfill material (45). Surface restoration of high infiltration areas should reduce acid mine drainage and aid in stabilizing mine pool elevations. Complete surface restoration will not be required to abate AMD in the Valley. Numerous projects are being undertaken to restore utility to the land and streams. The DER is undertaking a number of projects to reclaim mined lands. These projects include: reclamation of a refuse dump in Dickson City, filling of mine voids in the Hill and Minook sections of Scranton, and reclamation of the Northwest Dump seepage. The DER's project SL-139-1 along with hydrologic investigations conducted by the U. S. Geological Survey (23), should provide more insight and possible solutions to the

Northern Field's AMD problems.

Abatement of AMD from the Duryea, Old Forge and Jermyn Outfalls will probably be too costly if a treatment plant is required. For essentially complete abatement of AMD in the Lackawanna Valley, the two large outfalls, Old Forge, Duryea, and possibly the Jermyn Outfall, could be collected and treated for removal of iron and rely on the natural alkalinity of the Susquehanna River for neutralization. The Jermyn Outfall alone could be treated and possibly upgraded for drinking water to offset annual cost. Recent information indicates that this is not being considered (70).

Surface reclamation should reduce infiltration and any treatment cost. This would increase stream flow and natural neutralization of small discharges and increase the Lackawanna River's capacity to assimilate acidity. Full treatment of all AMD is not recommended due to cost, and it is assumed that natural neutralization by the Susquehanna River's flow is feasible for the purpose of estimating abatement cost. Cost estimates for required surface restoration, partial treatment and associated conveyance systems for the entire Lackawanna Valley are 6.9 million dollars initially and $0.6 million annually. Annual cost could be reduced depending upon the use of treated water by surrounding communities.

Lackawanna River to Nescopeck Creek

The Susquehanna River enters the Wyoming Valley, part of the Northern Field at West Pittston, just upstream from its confluence with the Lackawanna River (Plate 1). The river then flows toward the center of the Wyoming Valley and gradually westward leaving the Northern Field near Nanticoke. The Susquehanna River flows about 16 miles through the Wyoming Valley; traversing about two thirds of its length. In the past, discharges of AMD entering this reach of the Susquehanna River were derived from pumping and mine pool overflows, or gravity discharges. Presently mine pumping has practically ceased in the Wyoming Valley.

Information obtained during a hydrologic study of abandoned mines in the Wyoming Valley by the U.S.G.S. indicates that the Wyoming Basin has two large mine pool complexes along the northwest and southeast sides of the basin, each composed of numerous mines which have a common discharge (21). The southeast mine pool complex extends from and includes all mines from the Truesdale-Bliss, near Nanticoke, to the Delaware-Pine Ridge which underlies Mill Creek. Currently, the southeast mine pool discharges mainly from three 36 inch boreholes which were drilled into the South Wilkes-Barre mine, near Solomon Creek.

The northwest mine pool complex extends from and includes all mines from the Avondale-Grand Tunnel pool near Nanticoke, to the Exeter

pool near the town of Wyoming. Currently, the main discharge for this complex is the Buttonwood Airshaft. It discharges into Solomon Creek about one mile downstream from the three South Wilkes-Barre borehole discharges. Within each of the major two mine pool complexes there exist several mine pool levels. Each level is composed of a group of adjacent mines with common water level elevations. Mine pool elevations, which indicate possible flow directions, usually increase most toward the southeastern edge of the Wyoming Basin and decrease inward toward the center of the Basin. The highest mine pool elevations exist at the ends of the Basin in mines which are contained by unbreached barrier pillars.

The Susquehanna River (North Branch) is affected by the following AMD discharges. Downstream from the confluence of the Lackawanna and Susquehanna Rivers, the Susquehanna receives an average discharge of 2,300 ppd acid (70) from the Pittston Tunnel (Butler Water Tunnel) which has an average flow of 2.8 cfs. Acid, sulfate and iron concentrations range from 52 to 176, 260 to 880, and 1.2 to 25 ppm respectively. The Susquehanna River water quality is slightly affected by AMD from the Pittston Tunnel (70). Below this discharge the average river pH is 7.3. Alkaline and sulfate concentrations average 60 and 40 ppm respectively. At a point 4.5 miles downstream from the Pittston Tunnel a 40 inch borehole, recommended by a U.S.G.S. study (21) is currently being placed in the Henry-Prospect mine pool to reduce AMD discharging to the river and to stabilize mine

pool levels. A reduction in AMD should occur at the Buttonwood discharge when this work is completed. The water quality of Mill Creek has improved since pumping at the Delaware No. 2 shaft stopped in June 1972. Recent water quality information indicates that the Susquehanna River, below Mill Creek, maintains an average pH of 7.1 with average concentrations of 45 ppm alkalinity and 45 ppm sulfate.

From Mill Creek to Solomon Creek, the Susquehanna River does not receive significant amounts of AMD. Solomon Creek is affected by the two large mine discharges which drain the majority of the large northwest and southeast mine pool complexes (21). The Buttonwood Airshaft, which discharges the bulk of the northwest mine pool complex, has an acid range of 235 to 1,200 ppm (70). Other AMD indicators have a more narrow range of concentrations. Sulfate, iron, and manganese concentrations have median values of 1,800, 180, and 22 ppm respectively. Wide fluctuations in both flow and acid concentration yield acid loadings which range from 30,000 to 110,000 ppd (70). During the March 1971 to March 1972 period, relatively high flows yielded acid loadings averaging 100,000 ppd, with a flow of 33 cfs. Recent acid loadings, September to October 1973, average 21,800 ppd. Proposed boreholes intercepting part of the northwest mine pool complex should reduce flow and AMD loadings at the Buttonwood Airshaft.

One mile upstream from the Buttonwood Airshaft, three 36 inch

boreholes, completed by the DER in September 1971, have consolidated nearly all discharges of the southeast mine pool complex. This discharge is sometimes referred to as the South Wilkes-Barre Pumps. Pumps were never installed due to high costs and the possibilities of creating subsidence from fluctuating mine pool levels. Data collected since August, 1972 indicates that flows of 68 cfs discharge an average 260,000 ppd acid to Solomon Creek (70). Decreases of acid, sulfate, and iron concentrations during 1973 indicate that water quality trend is toward improvement, such as occurred at Old Forge and Duryea. After tropical storm Agnes, acid and sulfate concentrations averaged 940 and 3,367 ppm respectively. Water quality information collected in 1973 indicates lower average concentrations of 539 ppm acid and 2,075 ppm sulfate. Discharge of iron also represents a serious pollution problem. Recent data indicates an average discharge of 94,800 ppd acid is emanating from the South Wilkes-Barre Outfall (70).

About 1.5 miles downstream from the mouth of Solomon Creek the Susquehanna River receives AMD from Nanticoke Creek. Most of this mine drainage overflows the Askam borehole. The Askam borehole discharges water from the Truesdale-Bliss deep mine of the southeast mine pool complex. The Truesdale-Bliss and the adjacent Alden mines have a common mine pool elevation of about 575 feet (51). This elevation is approximately 40 feet higher than the adjacent Number 7 and Loomis mines which are enclosed by relatively solid barrier pillars. The Askam borehole discharges an

average 71,000 ppd acid with a flow of 18 cfs (70). Concentrations of mine drainage indicators have remained stable during 1973. Average concentrations of acid, sulfate, and iron are 727, 2,550, and 407 ppm respectively. River water quality information indicates that the Susquehanna River retains its alkalinity and has pH's of 7.0 downstream from Nanticoke Creek.

About 1.5 miles downstream from the mouth of Nanticoke Creek the Susquehanna River receives AMD from Newport Creek, the last major source of mine drainage emanating from the Northern Field. Newport Creek watershed has extensive coal outcroppings which have been stripped and only partially reclaimed. The Newport Creek area is still being extensively stripped. One active deep mine, Glen Nan, operated by the Blue Coal Company, is currently pumping mine water into Newport Creek (70). This is the dominant source of AMD entering Newport Creek and represents about half of the acid load recorded at its mouth. Very limited natural runoff during normal and low flow periods is contributed to Newport Creek, which is comprised mainly of sewage and AMD effluent. At the mouth of Newport Creek a flow of 25.7 cfs contributes an average 165,000 ppd acid to the Susquehanna River (70). Less than half of this flow is pump discharged. Average acid, sulfate, and iron concentrations are 1,300, 2,900, and 600 ppm respectively.

About nine miles downstream, the Susquehanna River receives AMD from one remaining minor source emanating from the Mocanaqua Tunnel near the mouth of Black Creek. This outfall discharges an average 6,200 ppd acid to the Susquehanna River (70). Concentrations of AMD indicators have remained relatively stable since 1966. An average flow of 2.5 cfs conveys an average 320 ppm acid, 1,000 ppm sulfate, and 120 ppm iron to the Susquehanna River. The Susquehanna River, downstream from the Northern Field remains alkaline, but is seriously affected by iron and other mine drainage indicators.

The North Branch Susquehanna River, between the Lackawanna River and Nescopeck Creek, undergoes its most serious water quality degradation and from which it rapidly improves farther downstream. Acid slugs may affect the Susquehanna south of Nescopeck Creek when high flows follow extended low flow periods.

Abatement of AMD in the Wyoming Valley will require the following measures. Extensive surface restoration of all areas of high infiltration will be required to promote surface runoff and improve streams with low concentrations of AMD indicators. Implementation of recommendations resulting from U.S.G.S. hydrologic studies should aid in decreasing mine pool circulation, and contact time of water with acid-forming materials. Abatement measures should aid in preventing both AMD and subsidence problems. Treatment and mine pumping should be used to abate AMD which

cannot be prevented or tolerated. After deep mine pumping stops in the Newport Creek area, natural inundation will reduce AMD concentrations and flows. History of AMD reductions in the Lackawanna Valley indicates that substantial decreases in AMD should occur after deep mine activities in the Wyoming Valley have ceased. Alkaline reserves of the Susquehanna River are not completely depleted by the 600,000 ppd acid from the Wyoming Valley and could possibly be utilized for natural neutralization, providing iron concentrations are low enough.

Estimates of abatement cost for the Wyoming Valley are somewhat difficult. Additional cost for treatment will be dependent upon the reductions of AMD caused by natural inundation of mines currently active, natural depletion of acid-forming materials, the effectiveness of preventive measures in decreasing infiltration, and the extent to which contact time of water with acid-forming materials can be reduced.

Cost of both preventive and follow-up treatment are estimated to be $9.0 million initially, $6.0 million preventive plus $4.4 million for treatment, and $1.0 million annually if extensive treatment is required. The DER (50) is currently conducting two AMD feasibility studies in the Wyoming Valley area. Under project SL 181-3, the Buttonwood, Warrior Run, and Nanticoke watersheds are being studied. Project SL 181-2 is being conducted just southwest of the SL 181-3 study area in the watershed of Newport Creek. The findings of these two projects should provide more realistic cost estimates of applicable abatement measures.

Nescopeck Creek

Nescopeck Creek drains 172 square miles, nearly all of this is located in Luzerne County. The southern part of the watershed is drained by Black Creek, a tributary to Nescopeck Creek, lying within the Eastern Middle Field. Black Creek is the only stream in the watershed draining an area underlain by substantial amounts of coal.

The extreme headwaters of Black Creek lie one to two miles south of the town of Freeland (Plate 1). Black Creek flows west past North Hazelton to its confluence with Stony Creek. Above this confluence Black Creek's acid load is an average 310 ppd with a mean pH of 6.2. Mean concentrations of other acid mine drainage indicators are 1.4 ppm iron, 102 ppm sulfate, and 1.3 ppm manganese. Eight miles farther downstream Black Creek's water quality improves, and the stream has an alkaline load of about 400 ppd. Two miles further downstream Black Creek receives nearly all of its acid mine drainage from the Gowen and Derringer Tunnels, discharging an average 4,800 and 3,800 ppd acid respectively (70). Black Creek remains acid to its confluence with Nescopeck Creek. At its mouth Black Creek contributes 4,900 ppd acid to Nescopeck Creek and has a flow of 22 cfs (72). Black Creek actually improves the water quality of Nescopeck Creek. Nescopeck Creek receives

essentially all of its acid mine drainage from Little Nescopeck Creek. Two miles north of Hazelton Little Nescopeck Creek receives an average discharge of 100,800 ppd acid (70) from the Jeddo Tunnel. The Tunnel was driven south into Buck Mountain toward the Black Creek Coal Basin (63). At its mouth Little Nescopeck Creek contributes an average 98,400 ppd acid (70) to Nescopeck Creek. At its mouth, Nescopeck Creek contributes 71,518 ppd acid to the Susquehanna River.

The Jeddo Water Tunnel is one of the larger single discharges of acid mine drainage in the Anthracite Region. Water quality and flow information for a five year period indicates the tunnel discharges an average acid load of 100,800 ppd to Little Nescopeck Creek. Flow ranges from 32 to 85 cfs, with a mean of 54 cfs. Values of pH range from 2.9 to 3.4, with a mean value of 3.2. Acidity ranges from 164 to 480 ppm with a mean 360 ppm. Sulfate, iron, and manganese concentrations range from 542 to 1,630, 14 to 35, and 10 to 30 ppm respectively, with mean concentrations of 788, 23, and 17 ppm respectively.

If the Jeddo Tunnel discharge could be eliminated, this alone would essentially clean up Nescopeck Creek, except for a small section of Black Creek downstream from the Gowen and Derringer Tunnel discharges. Water quality information for Nescopeck Creek, upstream from the confluence of Black and Nescopeck Creeks, indicates that sufficient alkalinity would be available to neutralize Black Creek's acidity in the absence of the

Jeddo Tunnel discharge.

Open pits left by past strip mining operations in the Nescopeck Creek Watershed cover a minimum of 2,000 acres (45). A minimum of 163 million cubic yards of backfill material would be required for original contour regrading. Backfill deficits will require the use of breaker waste or other refuse to supplement material needs. Nearly 70 percent of the strip pits are located in the areas covered by the Hazleton and Conyngham 7.5 minute quadrangle map (45). Restoration of all this land is not economically feasible. Diversion of flow away from strip pits, and stream channel repair, with some surface restoration should reduce the average flow from the Jeddo Tunnel. Reductions of acid mine drainage could also be accomplished by breaking mine pool circulation, and preventing long distance communication or contact time with acid-forming materials. A mean discharge of 54 cfs indicates that water is accumulating from a large area and traveling long distances (necessitated by the shape of the basin). Small changes in concentrations of acid mine drainage indicators with variations in flow indicate that a large amount of reactants are always available. A pH of 3.1 was recorded during higher than average flow, accompanied by nearly maximum concentrations of sulfate, iron, and manganese.

Under the DER's project SL-174 feasibility studies were conducted to determine by what methods acid mine drainage discharging from the Jeddo Tunnel could be minimized or eliminated from the

Nescopeck Creek Watershed. Currently investigations are proceeding to determine if this water could be utilized by the town of Hazleton (44). This would essentially pay some of the cost of abatement, thereby providing a more suitable economic solution to the problem. Utilization of treated mine drainage by public water companies essentially increases benefit/cost ratios by lowering cost. Abatement within the Nescopeck Creek Watershed will probably include some surface restoration measures and alteration of mine pool flow. Treatment for local water use should greatly reduce annual cost. Abatement cost estimates based on current projects within the Anthracite Region are 7 million dollars for preventive measures, and $2.2 million for treatment measures with additional annual cost estimated at $400,000. This cost is estimated for nearly 90 percent effectiveness. The remaining acid mine drainage will be neutralized by alkaline reserves within the watershed.

Catawissa Creek

The Catawissa Creek Watershed covers an area of 155 square miles. The headwaters of Catawissa Creek and Tomhicken Creek, a major tributary to Catawissa Creek, drain the southern part of the Eastern Middle Anthracite Field. The headwaters of Catawissa Creek are adjacent to the headwaters of the Lehigh and Schuykill River Watersheds, and have ground water communication due mainly to mining. Catawissa Creek flows from the town of McAdoo in Schuylkill County westward through part of Luzerne County to its confluence with Tomhicken Creek near Zions Grove (Plate 1). In this reach the Catawissa Creek leaves the coal measures just southeast of the town of Sheppton. Tomhicken Creek flows westward to its confluence with Catawissa Creek just west of the Eastern Middle Coal Field.

The headwaters of Catawissa Creek are affected by AMD emanating from a part of the Eastern Middle Field, contained almost entirely within Green Mountain. Structurally the coal lies in a synclinal basin which parallels Green Mountain. In the east and west ends of the basin the axis plunges nearly 3,000 feet and then rises to the surface. As deep mining progressed in the basin it became necessary to drive two water level tunnels toward the bottom seam (Buck Mt. vein) at the lowest elevations to provide a gravity discharge for the mine pool and prevent inundation of recoverable coal reserves.

Part of the Catawissa Creek Watershed, centered around Green Mountain, was intensively studied by a consultant under the FWPCA's contract WA 66-21 (17). Portions of the consultants findings are discussed here.

As Catawissa Creek flows west from the town of McAdoo along the south flank of Green Mountain toward the village of Sheppton, it receives three significant discharges of AMD. Both Green Mountain water level tunnels discharge an average 5,440 ppd acid to Catawissa Creek (70). Bot tunnels are being considered for sealing since all seams of coal which min water comes into contact produce AMD (54). If these tunnels are sealed and the mine pool levels are raised, it is anticipated that some of the wate now passing through the acid seams will be rejected or remain above acid forming materials. New discharges resulting from high mine pool levels, would be monitored and treated as required. Before leaving the area undei lain by coal measures Catawissa Creek receives AMD from the Audenreid Water Tunnel,which was driven toward the town of McAdoo in an adjacent coal basin. The Audenreid Tunnel discharges an average 52,900 ppd acid and is the largest single source of AMD in the Catawissa Watershed accorc ing to DER's SL-135 project information. This tunnel, which was recently cleaned and timbered (45), is also being considered for sealing. If sealed, new or additional discharges may appear near Beaver Meadows in the adjacent Lehigh River Basin (45).

On the north side of Green Mountain, Tomhicken Creek flows generally west toward its confluences with Little Tomhicken Creek, Sugarloaf Creek, and Little Crooked Run in the eastern part of North Union Township. Downstream from the confluence of Tomhicken and Little Tomhicken Creeks the Cox #3 tunnel discharged from 1,400 to 3,400 ppd acid during 1972 to Tomhicken Creek. Cox #1 discharges about 1,300 ppd acid to Sugarloaf Creek, the last major tributary to Tomhicken Creek. It then leaves the coal measures shortly before its confluence with Catawissa Creek.

Low alkalinity reserves within the remaining downstream reaches of the Catawissa Watershed are not sufficient to neutralize all of the AMD from the headwaters region. Catawissa Creek discharges about 18,000 ppd acid to the Susquehanna River. Sediment loads are relatively low in the Catawissa Watershed, probably due to lack of coal processing plants, refuse banks along flood plains, and the lack of strip mine discharges.

Within the framework of present technology and economics, abatement of AMD in the Catawissa Watershed will depend upon the successful sealing of tunnels, restoration of areas of high infiltration including stream channels, full utilization of low-flow augmentation and natural neutralization, along with eventual treatment of remaining amounts of AMD indicators. Total pollution abatement cost estimates are 5 million dollars initially.

Shamokin Creek

Shamokin Creek drains a 138 square mile area, located mainly in Northumberland County. From the headwaters, it flows about 12 miles due west toward the town of Shamokin, from Shamokin it turns and flows approximately 7 miles north to the Village of Reed Crowl, and again it turns and flows west toward Sunbury.

Shamokin Creek is the northernmost watershed affected by mine drainage in the Western Middle Anthracite Field (Plate 1).

It is reported that Shamokin Creek is affected by eight major AMD discharges. The tributaries most affected by these AMD discharges are: North Branch Shamokin Creek, Quaker Run, and Carbon Run. Shamokin Creek is directly polluted by discharges entering the mainstream in and east of the town of Shamokin. North Branch Shamokin Creek is affected by a gravity discharge of 2,170 ppd acid from the number 4 drift. One half mile southwest of this outfall is an artesian discharge of 3,414 ppd acid to the North Branch Shamokin Creek (72). The mean flow of North Branch Shamokin Creek decreases from 1.4 cfs at stream mile 3 to only 0.25 cfs at its mouth indicating a loss of runoff to deep mine workings. The North Branch, at its mouth, has mean concentrations of 317 ppm acid, 617 ppm sulfate and 38 ppm iron. In the extreme headwaters of Shamokin Creek the stream flows

about 3 miles west through the town of Mt. Carmel to its confluence with the North Branch of Shamokin Creek. Upstream from this confluence Shamokin Creek carries an average of 1,370 ppd alkalinity and has a mean pH of 6.8. Mean concentrations of AMD indicators are 17 ppm iron and 92 ppm sulfate. The town of Mt. Carmel could be introducing some alkalinity to Shamokin Creek, which would account for its lack of acidity and high alkalinity.

One mile downstream of the North Branch Shamokin Creek, Locust Run, a tributary to Shamokin Creek, discharges 453 ppd acid to the main stream. Three AMD discharges alone contribute about 320 ppd acidity to Locust Creek. Two miles downstream from the confluence of Shamokin and Locust Creeks, Shamokin has a mean pH of 4.7 with 200 ppm acidity. Other mean concentrations of AMD indicators are 638 ppm sulfate and 77 ppm iron. This reach of stream is in need of channel repair work which is currently in the planning stage. Loss of stream water most likely augments a discharge of 10.4 cfs from the Excelsior pool overflow which discourages 8,800 ppd acid to Shamokin Creek (72). Shamokin Creek, upstream from its confluence with Quaker Run, receives a discharge of 840 ppd acid from the Greenback drift gravity overflow.

Quaker Run, near Kulpmont, receives a discharge of 5,300 ppd acid from the Scott gravity overflow through a strip pit. Just above the confluence of Shamokin Creek and Quaker Run both streams are carrying an

average of 9,000 and 6,600 ppd acid (72) respectively and one mile downstream from the confluence the mainstream conveys 13,000 ppd acid with a mean flow of 15.7 cfs. Mean sulfate and iron concentrations have increased to 740 and 120 ppm respectively.

Southeast of the town of Shamokin, Buck Run is affected by the Big Mountain drift and shaft which discharge 540 ppd acid to Shamokin Creek. Shamokin Creek, one mile further downstream in the town of Shamokin, receives 320 ppd alkalinity from Coal Run and 3,260 ppd acid from Carbon Run. Coal Run has mean concentrations of 220 and 8 ppm sulfate and iron respectively, with a mean pH of 6.1. The Sterling gravity discharge of 6,200 ppd acid is the single largest contributor of AMD to Carbon Run. Just downstream from the confluence of Carbon Run and Shamokin Creek the Glenburn Pump Discharge, when pumping, discharges 5,800 ppd acid to Shamokin Creek.

Just north of the town of Shamokin, Shamokin Creek follows north out of the Western Middle Anthracite Field. At this point, nineteen miles from the mouth of the Shamokin Creek, the stream has a mean acid load of 31,700 ppd, with a mean flow of 40.5 cfs, and concentrations of 88 ppm iron, 5.2 ppm manganese, and 626 ppm sulfate. At its mouth, Shamokin Creek, from 1966 to 1968, discharged an average 42,000 ppd acid to the Susquehanna. The above mentioned point sources of AMD discharge a total of about 33,400 ppd which essentially equals the acid load of

Shamokin Creek as it departs from the Western Middle Field. Other minor sources of AMD are neutralized by alkaline reserves within the watershed.

A minimum of 2,000 acres of open strip pits will require about 120 million cubic yards of backfill material for complete original contour restoration. Much of this needed material is absent due to the volume of coal removed.

Under the Department's Project SL-113, AMD studies were conducted to determine methods of abatement in Shamokin Creek's watershed. The DER recently awarded a contract for surface restoration work east of Mt. Carmel (45). Plans are currently being finalized for additional restoration work three to five miles east of Shamokin. Abatement cost estimates for the Shamokin Creek Watershed are 6.2 million dollars for preventive measures and 2.2 million dollars initially for treatment and $400,000 annually.

Mahanoy Creek

The Mahanoy Creek Watershed drains an area of 155 square miles, part of which is in the Western Middle Anthracite coal field. Mahanoy Creek flows southwest from its headwaters in Schuylkill County, through part of Columbia County to its confluence with the Susquehanna River in Northumberland County (Plate 1). It discharges 3,100 ppd alkalinity (72) to the Susquehanna River, but suffers extreme water quality degradation in the headwaters. Streams which contribute significant amounts of AMD are Waste House Run, North Mahanoy Creek, and Zerbe Run. Although there are many sources of AMD in the Mahanoy Creek Watershed, only the larger sources are discussed.

In the extreme headwaters Mahanoy Creek is affected by an acid discharge of 1,700 ppd from the Morris Tunnel (72). One mile downstream just northeast of Mahanoy City two borehole discharges, the barrier east gravity discharge, and an artesian flow contribute 800 and 2,700 ppd acid to Mahanoy Creek respectively. After tropical storm Agnes, the DER (45) cleaned the above boreholes to prevent excessive heads of water from building up in the mines. North Mahanoy Creek contributes an average of 4,100 ppd acid to Mahanoy Creek. The single largest source of AMD in the North Mahanoy Creek Watershed is the Springdale intermittent pump discharge, which is currently active (45). During pumping it discharges an ave

4,600 ppd acid with a flow of 2.83 cfs. Two miles downstream from Mahanoy City, Waste House Run discharges 11,000 ppd acid to Mahanoy (72) Creek and is one of the more heavily polluted tributaries of Mahanoy Creek. Currently the Reading Coal Company is pumping 9,700 ppd acid to Waste House Run. Just northeast of Girardsville, Shenandoah Creek discharges only 8.2 ppd acid to Mahanoy Creek. An artesian gravity discharge yields 2,900 ppd acid to Shenandoah Creek which neutralizes most of this stream's alkalinity. Just before the confluence of Mahanoy and Shenandoah Creeks two artesian discharges contribute 15,000 and 9,000 ppd acidity to Mahanoy Creek. In addition to these discharges the Bass intermittent pump discharge, when active, contributes 12,200 ppd acid to Mahanoy Creek. About one mile northeast of Ashland, Big Mine Run yields 1,700 ppd alkalinity to Mahanoy Creek. The largest single AMD contributor on Big Mine Run is the Big Mine Run gravity discharge of 9,100 ppd acidity. This acidity is neutralized by alkalinity from the Girardsville Tunnel discharges and the Hammond discharge east of Ashland.

From Ashland, Mahanoy Creek flows southeast nearly three miles and then, at Gordon Village, continues to flow southwest for about 20 miles to its confluence with Zerbe Run southwest of Treverton. In this reach of stream the Mahanoy Creek has no additional sources of AMD other than an

artesian discharge of 1,200 ppd alkalinity which enters a tributary, sometimes called Lavelle, to Mahanoy Creek near Locustdale. Ten miles southwest of Gordon, Mahanoy Creek has a mean pH of 6.3 and was never recorded below 6.0. The mean net alkalinity and iron concentrations are 55 and 10 ppm respectively. Eight miles further downstream all mean concentrations of AMD indicators, including manganese, iron, and sulfate continue to decrease.

Zerbe Run contributes a mean acid load of 7,600 ppd (72) to Mahanoy Creek, ranking it as one of the most severely polluted tributaries to Mahanoy Creek. Zerbe Run, at its mouth, has mean concentrations of 800 ppm sulfate, 30 ppm iron, and 9 ppm manganese. Available information indicates the major contributors of AMD to Zerbe Run are the North Franklin pump discharge of 4,800 ppd acid, and a discharge from an abandoned drift of 1,300 ppd acid. The Trevorton Tunnel is the largest contributor of AMD to Zerbe Run, with an acid discharge of 12,000 ppd according to EPA files. Alkaline reserves of Mahanoy Creek are more than sufficient to neutralize the AMD introduced by Zerbe Run. At its mouth, Mahanoy Creek contributes 3,100 ppd alkalinity to the Susquehanna River. Water quality analysis of Mahanoy Creek indicate that a wide range of AMD indicators exist. These conditions are probably controlled by mine pool levels and circulation, rate of overflow, intermittent pumping, precipitation,

and coal processing effluent. Major sources of AMD alone contribute an average acid load of 67,400 ppd to Mahanoy Creek when the above mentioned pumps are active. When intermittent pumping eventually ceases mine pool surfaces will elevate until gravity overflows occur. The amount of water overflowing is usually less than the amount coal companies pumped from the pools due to rejected recharge. A minimum of 2,684 acres of land within the Mahanoy Watershed was stripped and, in some cases, only partially backfilled. The amount of backfill material required for original contour restoration is estimated at a minimum of 280 million cubic yards (45). Complete restoration of strip pits where thick and numerous coal seams have been removed is not economically feasible because of extensive backfill deficits. If areas requiring extensive amounts of backfill material are in close proximity to acid-producing refuse banks, backfilling with refuse may be done at lower cost with reductions of MD achieved in both areas. The enormous cost of complete surface restoration is as prohibitive as continual treatment cost, which was once considered as a possible solution to Mahanoy Creek's AMD problems. Sealing of extensive deep mines in other watersheds of the Anthracite Region has not always been feasible due to the uncertainty of success and the possibilities of creating more problems, such as subsidence and flooding of basements in homes.

Consideration should be given to the execution of hydrologic

investigations within the watershed to determine the most effective means by which the formation of AMD could be minimized at the lowest cost. Currently the solution to abating AMD in the watershed appears to depend on the success of implementing the following abatement methods: (1) areas of high ground water recharge associated with highly acid seams should be restored, (2) proper placement of boreholes could route acid and non-acid water into alkaline rock units to neutralize and increase the alkaline reserves of the watershed, (3) boreholes could also drain mine pools and prevent circulation of water, thereby decreasing contact time with acid-forming materials, (4) tributary watersheds could be used for low flow augmentation or dilution; and (5) the remaining AMD which cannot be abated or tolerated should be neutralized. The percent effectiveness of preventive measures, natural neutralization, and low flow augmentation would decide to what extent treatment is required. First costs are estimated to be about $13.9 million, including $2.9 million for treatment, $8 million for surface restoration, and $3 million for hydrologic investigations, ground water monitoring, boreholes, small dams, and mine seals. Annual costs are estimated at $400,000 for maintaining treatment, clearing boreholes and repairing conveyance systems.

Rausch Creek

An extensive mine drainage investigation (February 1968 to February 1969) conducted in the Rausch Creek Watershed was accomplished under Pennsylvania Department of Environmental Resources Project SL-112 (1). Portions of the project's findings are recorded here.

Rausch Creek Watershed encompasses 6,300 acres (about 10 square miles). It is a sub-watershed of Pine Creek (a tributary to the Mahantango Creek) and lies mostly in Western Schuylkill County in Hegins and Porter Townships, and extends partially into Williams Township, Dauphin County (Plate 1). Topographically Rausch Creek Watershed is bounded by two mountains, Bear Mountain to the north and Big Lick Mountain to the south. Rausch Creek appears on a map as an inverted "T". The horizontal line being the east and west branch of Rausch Creek. These two branches flow in the valley between Bear Mountain and Big Lick Mountain. The confluence of these two branches forms Rausch Creek (the stem of the inverted "T") which flows in a northerly direction through the gap in Bear Mountain to its confluence with Pine Creek. There are no towns within the watershed, however, the town of Valley View is just east of the confluence of Rausch Creek and Pine Creek. West Branch Rausch Creek originates in a swampy area 3.3 miles west of the

confluence with the East Branch. East Branch Rausch Creek originates in a large strip mine on the north slope of Big Lick Mountain 2.1 miles east of the confluence with West Branch Rausch Creek, and flows northerly approximately 1.6 miles to its confluence with Pine Creek. The total stream length of Rausch Creek (including the east and west branches) is 7.0 miles.

At the time of the study, there were twenty-eight active and nineteen abandoned mine operations. These produced a new pollution load of 12,000 ppd acid, 25,850 ppd sulfates, and 3,050 ppd iron in Rausch Creek at the gap in Bear Mountain (1).

The major pollution sources in the watershed are listed below in decreasing order of acid loads.

1. Markson Columnway is an abandoned operation located just north of the confluence of the two branches of Rausch Creek and east of Rausch Creek. It discharges directly into Rausch Creek and has an acid load of 4,150 ppd.

2. Valley View Tunnel is an abandoned operation discharging 2,500 pounds of acid per day into West Branch Rausch Creek. It is located just west of the confluence of the west and east branches of Rausch Creek on the south side of West Branch Rausch Creek.

3. Buck Mountain Drift is an abandoned operation discharging 1,650 pounds of acid per day into Rausch Creek. It is located west of Rausch Creek just north of the confluence of the east and west branches of Rausch Creek.

4. Good Spring Number One Airhole is an abandoned operation discharging 1,050 pounds of acid per day into East Branch Rausch Creek. It is located on the north side of East Branch Rausch Creek approximately 1.3 miles upstream from the confluence of the East and West Branch of Rausch Creek.

Various abatement procedures were considered in the report. It was concluded that mine sealing was futile because of non-uniform geologic structures. Mine inundation in some areas would flood other active mines or force acid water into the Wiconisco Creek Watershed. Two categories of abatement were recommended. They were surface treatment and water treatment. Surface treatment involved surface drainage improvement. This could be accomplished by backfilling and revegetating strip mines, constructing diversion ditches, flume construction, and rechanneling of streams. The total estimated area is 310 acres. The total cost to restore the watershed to its original drainage pattern is estimated to be $1,400,000.

Three schemes of water treatment were analyzed and the most economical method was recommended. A single universal treatment plant located north of Bear Mountain Gap along Rausch Creek was chosen, because it could treat all of the water draining through the watershed. The cost for such an operation is $280,000 annually for the first 40 years. This is equal to a treating cost of $0.10 per 1000 gallons of water. Annual cost includes construction costs, engineering and supervision costs, debt

service at 6% interest for 40 years amortization, operation and maintenance, and sludge disposal.

It was recommended that surface treatment should be completed first. Then the water quality should be analyzed for percent reduction of acid caused by the surface reclamation. After this is completed, the size of treatment plant needed can be determined to completely clean up water entering into Pine Creek from the Rausch Creek Watershed.

With the abatement of acid mine drainage pollution in Rausch Creek Watershed, 27 miles of streams from the Susquehanna River to Rausch Creek (8 miles of Pine Creek and 19 miles of Mahantango Creek) could be classified as clean unpolluted streams.

The proposed treatment plant was constructed and nearly operational when flooding related to tropical storm Agnes in 1972 caused severe damage to the plant. Currently the plant is undergoing repair. The cost of damage was reported at 0.25 million dollars. Initial cost for the treatment facilities is about 2.2 million dollars initially and 0.3 million annually. The plant is designed for 10 mg/d with holding basins (45 designed for 20 mg/d. East Branch Rausch Creek is reported to have significant yields of coal fines from a coal prepartion plant. West Branch Rausch Creek was re-aligned by the DER and cleaned to clear a swamp area and steepen the grade of the channel (45).

Wiconisco Creek

A mine drainage investigation conducted for one year in the Wiconisco Creek Watershed was accomplished under Pennsylvania Department of Environmental Resources' Project SL-170, and completed January, 1973 (29). Part of the project's findings are reported here.

The 121 square mile Basin is oriented northeast-southwest with its headwaters on the flanks of Big Lick, Stony, and Broad Mountains. The Wiconisco joins the Susquehanna River just north of Millersburg after gradually dropping vertically 520 feet in just 27 miles from its headwaters.

In the extreme headwaters of Wiconisco Creek, Keefer Tunnel discharges an average of 594 ppd acid with an average flow of 1.15 cfs. About one mile downstream Porter Tunnel, currently operated by Kocher Coal Company, has a discharge of 1,069 ppd acid which is being treated. Two and a half miles below the confluence of the Porter and Keefer Tunnel discharges, Wiconisco Creek has an acid load of about 1,000 ppd with a slightly improved pH of 3.8. At Tower City, the Wiconisco Creek has an average pH of 4.4 and an average acid load of 510 ppd. This improved water quality is due to dilution by good quality water from several tributaries near Tower City. Three miles downstream from Tower City,

Wiconisco Creek is reported to have an average of 370 ppd alkalinity with an average flow of 19.5 cfs. Just west of Williamstown, Big Lick Tunnel, the first alkaline deep mine discharge, contributes an average of 458 ppd alkalinity to Wiconisco Creek. Two miles farther downstream, just east of Lykens, water quality is vastly improved. Wiconisco Creek, upstream from its confluence with Bear Creek has an average alkaline load of 1,252 ppd and a pH of 6.3. Bear Creek contributes an average of 4,511 ppd alkalinity to Wiconisco Creek. The only major source of acidity to Bear Creek is the Lykens Water Level Tunnel with an average acid discharge of 458 ppd. Farther downstream Bear Creek receives several large alkaline discharges,which cause the stream to become alkaline at its mouth. Other discharges to Bear Creek contribute no acid but do yield 432 ppd of iron; 7,678 ppd sulfate; and 4,022 lbs/day alkalinity with an average pH of 6.4. Just west of Lykens, Rattling Creek contributes only 80 ppd acid to Wiconisco Creek, which remains highly alkaline to its confluence with the Susquehanna River near Millersburg.

Water quality data collected downstream from all mine drainage discharges at the mouth of Wiconisco Creek indicated an average of 6,700 ppd aldalinity, 575 ppd iron, and 15,250 ppd sulfact with a pH of 6.8. Four sources (Porter, Tower City #1, Keefer, and Lykens

Water Level Tunnels) account for 97 percent of the acid discharging to Wiconisco Creek. Breaches in deep mine barriers allow mine drainage to pass into the watershed from an adjacent basin to the northeast. Rausch Creek to the north also receives some acid mine drainage from the Wiconisco Creek Basin. The large number of entryways and tunnels increase infiltration and make drainage control somewhat unpredictable. Mine drainage to the Wiconisco Creek causes the stream to run acid for 10 miles from a point 3 miles east of Tower City to between Williamstown and Lykens to the southeast. Recordings of pH never exceeded 6.0 during the sampling period. Measured pH's ranged from 3.5 at the headwaters to 6.0 near Williamstown. Just upstream from Bear Creek the Wiconisco is of good water quality. However, farther upstream the Wiconisco Creek is rendered useless as a source of fresh water or for recreational purposes.

Consideration was given to a full range of abatement methods. Of all abatement methods considered, mine sealing was eliminated due to complexities caused by extensive deep mining and associated entryways. The Porter Tunnel, which is currently being worked, would be flooded if the Tower City Tunnels were sealed. The abatement plan recommended complete strip mine restoration, followed by a water sampling program to determine the amount of lime treatment required to abate the remaining 75 percent of the coal mine drainage.

Complete restoration of strip mined areas which allow infiltration and surface communication with the Lykens area discharges is estimated to cost $1,009,000. Reclamation of the areas in close proximity to the Porter discharges is estimated to cost $2,342,000. Additional surface reclamation work will cost an additional $60,000 for a total of $3,411,000 (all estimates based on December 1972 costs). This surface reclamation work should provide for a permanent reduction of 25 percent of the mine drainage in Wiconisco Creek and restore the adjoining land surface (659 acres). An average 25 percent reduction of acid mine drainage will result in the elimination of 914 ppd acid, 238 ppd iron, and 4,388 ppd sulfate.

A lime treatment follow-up program, which assumes a certain decrease in flow and concentration of acid mine drainage indicators, should eliminate the remaining 75 percent of the pollutants. The abatement of the remaining AMD emanating from the Lykens source area is estimated to cost $200,000 initially and $20,000 annually. This will bring the total abatement of AMD in the Wiconisco Creek to 80 percent. The remaining 20 percent, associated with the Porter Mine area, will cost $300,000 initially and require an annual expenditure of $30,000.

As of January, 1973, the Pennsylvania Department of Environmental Resources decided to proceed with two abatement plans on State Game Lands (57), which will eliminate 220 ppd acid, 132 ppd iron,

and 1,952 ppd sulfate, State Game Land's projects will reclaim some land adjacent to Bear Creek at costs approaching $0.2 million.

Swatara Creek

Swatara Creek drains 576 square miles just east of Harrisburg, Pennsylvania. The Swatara Creek discharges an average of 630 mg/d to the Susquehanna River at Middletown. The watershed yields, on the average, 1.69 cfs per square mile. This accounts for 23 of the 45.5 annu inches of precipitation. The ground water increment is 8.8 inches annuall for the watershed. An average of 45.5 inches of precipitation annually makes 1,239 mg/d available to the watershed. Of this amount 580 mg/d is evaporated and transpired while 56 mg/d is utilized by man with 27 mg/ being returned to drainageways and the ground water supply. Of the 56 mg/d, 25 percent is for public supply and 75 percent for industry and private supply. Stream flow diversion is used for 86 percent of the public and 27 percent of the industrial water supply (34).

During high and moderate flows, water quality is compatible with the watershed's needs in most areas. At low flows AMD and sewage contamination necessitates considerable treatment before use. Sites for storage of surface waters exist in the Valley and Ridge Province (figure 2) which is close proximity to the southern coal measures. It has been reported that 30 40 percent of the annual flow could be stored for release as low-flow augmentation for dilution of AMD and sewage assimilation (34). These areas have a well-vegetated surface underlain by resistant sandstones and yield

low sediment loads compatible with long reservoir life.

Average annual sediment yields of 550 to 650 tons per square mile are characteristic of the heavily stripped mined parts of the watershed (34). Agricultural lands yield from 300 to 350 tons per square mile on an average annual basis. Heavily forested lands over siliceous rocks (sandstones and sandy shales) have the lowest sediment yields (30 to 35 tons) in the watershed. Such areas are typical of those found in the coal measures. Surface mining and other practices of the coal industry increase sediment yields as much as 18.5 times. In extreme cases an average of 15,000 tons of sediment per square mile per year are transported from mined areas (34). Precipitation and surface runoff data for the watershed clearly indicate the need for vegetation in stripped areas. Transpiration accounts for a considerable amount of the precipitation intercepted by the watershed during five months of the year. Surface restoration, including proper vegetation, should reduce both sediment and AMD yields of the Swatara Creek Watershed. In many respects it is a model of other watersheds in the Anthracite Region which have similar problems.

Swatara Creek

Northeast Headwaters Area

An extensive study of this area of Swatara Creek was conducted under the Pennsylvania Department of Environmental Resources, Project SL-126-1. Portions of the project's findings are recorded here (19).

The northeastern headwaters area of Swatara Creek encompasses an 18.7 square mile portion of the headwaters, which is tributary to the headwaters of Swatara Creek, as well as Panther and Black Creeks. Of this area about 10 percent or 1.9 square miles has been disturbed by active and inactive surface mining operations. Active coal mining in the area has accounted for the production of 125,000 tons of coal during 1970, and may continue for several years. The four operations which continued to mine in 1971 had produced 60,000 tons of coal in 1970. The extent of the deep mine pools will play a major part in deciding the future of coal mining in the area. Mine drainage associated with active deep and strip mines was reported to be insignificant.

The headwaters of Swatara Creek flows about five miles southeast toward the northern flank of Sharp Mountain where it is met by Panther Creek (Plate 1). Above this confluence Swatara Creek carries an average of 752 ppd acid with an average pH of 4.0 and an acid concentration of 78 ppm.

After its confluence with Panther Creek, Swatara Creek continues to flow three miles along Sharp Mountain southwest to its main confluence with Good Spring Creek. This stream is also affected by AMD from the northcentral and northwestern areas of the Swatara Creek headwaters. Before this confluence Swatara Creek has an average acid load of 1,700 ppd. Stream flow increases nearly three times, and acid concentrations are reduced by 18 ppm to an average of 60 ppm. Black Creek, a tributary of Swatara Creek has no AMD discharges but does have a background level of 21 ppm acidity.

A significant amount of acid mine drainage pollution in this Swatara Creek area is attributed to the following:

1. Streams' headwaters originate in areas of conglomerates, sandstones, and shales, which together add little to the buffering capacity of streams which are easily affected by AMD. Overlying rocks of sandstone and shale are often interbedded with iron sulfide materials which can create acid waters.

2. Interception of natural surface runoff by areas which have not been reclaimed (nearly 2.0 square miles), and eventual infiltration augments deep mine discharges.

3. Orientation of acid coal seams increases contact time with acid-forming materials and water which travels long distances.

4. Continuous seepage through refuse piles containing highly acid-forming materials contributes large amounts of acid to this area and occasional acid slugs.

During a sampling program, from December 1970 through September 1971, fifty-one mine drainage discharges were sampled periodically. Discharges from only four discharges (three deep mine pool overflows and one refuse pile) were found to contribute 93 percent of the acid load recorded in the northeast area of the headwaters. Individual discharges ranged from flows of 0.039 to 2.84 mg/d, iron concentrations from 0.1 to 71 PPM and acid concentrations from 25 to 4,420 PPM. These produced a combined net pollution load (average) of 220 ppd iron; 3,720 ppd acid; and a flow of 4.25 mg/d.

The four major pollution sources in the study area are listed below in decreasing order of acid loads:

1) A continuous seepage of surface water through a refuse pile 1/4 mile east of Newton Village, and 1/3 mile south of U. S. Route 209 in Reilly Township, which discharges into a large overflow pond and has an acid load of 2,000 ppd.

2) A continuous discharge from a deep mine through a rock tunnel. This discharge has an acid load of 591 ppd and is located 1/2 mile east of the confluence of Swatara and Panther Creeks in Reilly Township.

3) A continuous overflow from a deep mine pool through a backfilled strip mine. This discharge, having an acid load of 446 ppd, emanates from a drift mine 1 mile northwest of Newton Village in Reilly Township.

Various abatement procedures were considered by the consultant with emphasis given to achieving water quality criteria set by the DER. Different combinations of preventive and treatment measures were considered and one plan was chosen. This plan involves clearing of 750 feet of stream channel, lining of 4,430 feet of stream channel, along with 8,700 feet of diversion ditching. Other major phases of the plan include restoring 380 acres of strippings, curtain grouting, sealing a rock tunnel, and moving nearly 534,000 cubic yards of refuse. Treatment measures of the plan include construction of sewers, equalization basins, channels, and one small treatment plant designed for wet weather flow.

The effectiveness of the abatement plan is anticipated to yield a 98 percent reduction of iron (220 ppd), and 97 percent reduction of acid (3,640 ppd). Preventive measures alone should account for an estimated 93 percent reduction of the acid ppd. Total project costs are estimated at $9,950,000 initially. Treatment project costs alone are estimated at $220,000 initially, with an additional annual cost of $76,000. It is anticipated that after implementation of the abatement projects most of the tributaries will achieve nearly normal water quality, or have background levels only of mine drainage indicators. The abatement plan recommended for the northeast area should reduce the pollution observed in the adjacent central area. The reduction of 170 ppd iron and 852 ppd acid

should be realized in this area if the plan is implemented. If the percent of effectiveness is achieved, the northeast area will return at least 3.4 million gallons of water per day to downstream users, and also provide water for local users in the area.

Currently, extensive surface restoration is being considered for the northeast area in connection with the removal of the area's greatest source of acid, a refuse pile east of Newton Village (45).

Northcentral Headwaters Area

The northcentral area, encompassing 14.9 square miles, was investigated under the DER Project SL-126-2. Some of the information (7) generated during this study is presented here.

During the study, water quality from discharges of active mines was reported, along with abandoned sources. Active mines in the central area had a combined yearly average production of about 90,000 tons of coal during 1969 and 1970. This represents about 1 percent of all the anthracite coal mined in Pennsylvania. Nine mines, utilizing about seven men each, produced about 10,000 tons per mine. Since April 1968, all companies operating active mines, for which the Environmental Quality Board would normally require treatment, were contributing 15 cents per ton of coal mined to the DER.

Major tributaries of the northcentral area and their water quality status are as follows. Good Spring Creek flows about 5 miles nearly due east through heavily deep and strip mined sections of the Swatara Creek headwaters. Midway toward its confluence with Martin Run, Good Spring Creek has an average acid load of 612 ppd. Near Donaldson, Martin Run contributes an average of 354 ppd. East of Donaldson, Good Spring Creek

flows about two miles southeast to its confluence with Swatara Creek, just south of Red Mountain, one half mile south of Tremont. In this reach Good Spring Creek's acid load increases to an average of 8,962 ppd with an average flow of 35.5 cfs. The additional acidity is contributed from the following tributaries of Good Spring Creek. Besides Martin Run, AMD is also introduced to Good Spring Creek from Bailey Run, Hollenbach Run, and those areas tributary directly to Good Spring Creek,which bring the average acid load to 1,894 ppd. Below this point Good Spring Creek reaches its confluence with Gebhard Run, which receives acid loadings from its tributaries, Coal Run and Middle Creek. Water sampling and flow measurements at the mouth of Gebhard Run indicate that it's contributing 5,023 ppd acid to Good Spring Creek. The best stream in the area is Poplar Creek, which contains no acid and few strip mines. The tributaries of the northcentral area are carrying an average of about 5.25 times as much acid as the northeast area. The reasons for this are the increase in the number of mineable coal seams.

During the course of the "Operation Scarlift" project (7), 92 sample stations were established. These were tested twice a month, or monthly, depending on the severity of the pollution. Flows were measured by weirs and stream sections. During the sampling period, August 1969

to December 1970, the northcentral area main stream carried a maximum of 50,000 ppd acid and 10,870 ppd iron. Average for the area was 8,962 ppd acid and 953 ppd iron. At this location pH ranged from 3.3 to 4.4, acidity ranged from 120 t0 28 ppm, and sulfates from 2,600 to 130 ppm. Some of the more interesting findings of the central area were the high output of acid (61 percent) from overflowing mine pools, and the higher than expected acid production of refuse dump material which produced 32 percent of the total acid load recorded.

The main sources of pollution discovered during the study were abandoned deep mines and their associated overflows. These averaged a total of 5,909 ppd acid, or 61 percent of the total acid recorded in the area. Coal mine refuse was the second largest contributor with an average recorded daily production of 3,144 ppd acid or 32 percent of the total. Coal refuse in the area covers 420 acres, having a volume of 18,730,000 cubic yards. Strip mines alone contributed 4 percent of the total acid recorded. Coal Run, a tributary to Middle Creek which flows into Gebhard Run, is the most polluted stream in the central area. This is a result of overflows from two of the five large mine pools which discharge within the central area.

Major contributors of AMD pollution are listed below in decreasing order of acid loads:

1) The Tracy Overflow is located one mile east of Donaldson Village, discharging an average acid load of 4,294 ppd to Coal Run.

2) Tracy Airhole is located two miles west of Donaldson Village discharging an average of 794 ppd acid directly into Good Spring Creek.

3) Indian Head mine pool discharges 399 ppd acid directly into Coal Run and is located along T-571 one and one half miles east of Donaldson Village.

4) Colket Water Level Tunnel, located on Martin Run 1,000 feet upstream from Donaldson Village, discharges 382 ppd acid from a mine pool.

Abatement considerations were made in the following order. 1) Preventing or at least minimizing AMD formation at its source. 2) The remaining acid would be kept (if possible) from entering streams or placed where it is momentarily more tolerable. All remaining acid which could not be abated or tolerated would receive treatment recommendations.

Recommended first phase (preventive) type projects were estimated to cost $5,217,000 and should abate 45 percent of the AMD emanating from the central area. This includes partial regrading over specific strip pits and large areas over mine pools. Partial regrading should cost $2,645,000. Stream ditch relocation and construction is estimated to cost $950,000. Other costs are mine seals--$460,000; planting--$501,150; and dikes, plugs,

curtain grouting, etc.--$661,700.

A second phase was recommended to include the construction of a central lime neutralization treatment plant and collection system. Initial cost should be about $1,844,000 with annual costs for operation, maintenance, and the debt coming to $226,500. Both the first and second phases have a combined estimated cost of $7,061,800. The combined effectiveness is estimated at 86 percent of the pollution or 7,707 ppd acid. This price is not uncommon for the anthracite region, which suffers problems not encountered in the soft coal fields, where coal seams are not as thick or numerous.

Swatara Creek

Northwestern Headwaters Area

The northwestern area, containing the tributaries of Lower Rausch Creek and Lorberry Creek, underwent a preliminary engineering study under the DER's Project SL-126-3 (2). This study completed the DER's current investigations of the headwaters of Swatara Creek. This area is located in western Schuylkill County and covers 9.5 square miles or 6,120 acres. Rock units in the area, associated with the coal beds, convey water quite readily. Some mining engineers reported that 21 tons of water had been pumped for each ton of coal shipped. This area of the Swatara Creek headwaters is almost entirely underlain by coal.

The headwaters of Lorberry Creek are found at Rowe Tunnel. The stream flows generally southeast to its confluence with Lower Rausch and Swatara Creeks just south of Sharp Mountain. Stump Run, a tributary of Lorberry Creek, was reported to be a "clean stream" and dilutes the acidity of Lorberry Creek.

During the sampling period, June 1970 to June 1971, water samples and flow measurements were collected weekly (2). Thirty-eight pollution sources were found of which half were associated with active operations. Lorberry Creek, just before its confluence with Lower Rausch Creek,

carries an average acid load of 1,746 ppd. Lower Rausch Creek, at its mouth, has an average acid load of 1,216 ppd. Both tributaries together have an average acid load of 2,962 ppd. During wet weather conditions, Lower Rausch Creek and Lorberry Creeks increased their acid loads by 1,003 and 1,546 ppd respectively. The Rowe Tunnel, at the headwaters of Lorberry Creek, contributes 80 percent of the total pollution in the stream. The Rausch Creek Tunnel contributes about 93 percent of Rausch Creek's total pollution. Lorberry Creek's acidity, at the mouth, ranges from 15 to 45 ppm and Rowe Tunnel contributes 60 percent of the Creek's flow and its acidity ranges from 50 to 100 ppm. Other additions of acidity to Lorberry Creek are two deep mine discharges of nearly 1,000 and 350 ppd each. During the sampling period natural aeration and adsorption converted 66 percent of Lorberry Creek's ferrous iron to ferric iron, which is less harmful to biota. This, however, causes the deposition of large amounts of insoluble iron salts on the stream bottom.

Lower Rausch Creek has two major contributors of suspended solids, the Madenford Dredging Operation and the old Westwood Refuse Bank which contains 1,000,000 cubic yards of material spread over 120 acres. During high rainfall periods large amounts of sediment are washed into the Creek. Efforts, however, were made to prevent this condition. Lower Rausch

Creek does not experience a reduction of total iron concentrations along its full length. Ground water flowing through highly acid materials excavated for interstate highway 81 and strip mine runoff contributes 50 percent of th total iron. The remaining iron emanates from five abandoned operations – the greatest source among them being the Rausch Creek Tunnel. Peak sulf concentrations reaches 200 ppm and acidity ranges from 10 to 50 ppm at th mouth of Lower Rausch Creek. The Rausch Creek Tunnel is the largest co- tributor of acidity, with concentrations ranging from 112 to 213 ppm. Ther are no sources of alkalinity in Lower Rausch Creek.

Construction of treatment facilities will be required to abate som of the AMD. Water tight sealing of deep mines will, for the most part, not be feasible because little information regarding sub-surface conditions is available. "Crop falls" exist which augment infiltration to deep mine pools. The estimated costs of both preventive and treatment abatement measures were divided into the following three areas:

1) Lorberry Basin
2) Lower Rausch Creek upstream or north of U.S. 209
3) Lower Rausch Creek downstream or south of U.S. 209

Lorberry Basin's estimated cost of treatment is $168,200 for capital expend- tures with additional annual operating cost of $21,300 for a reduction of 98.8 percent of the AMD. A small cost, $2,900, for levees and rechanneling should abate a remaining 1.2 percent of the pollution for a total cost of

$171,100 initially and $21,300 annually. Lower Rausch Creek (upstream) treatment costs are estimated at $100,700 capital and $8,800 annually for an effectiveness of 94.7 percent. Preventive measures will further reduce pollution by 5.3 percent and bring the total cost of $104,500 initially and $8,800 annually. Lower Rausch Creek (downstream) treatment costs are estimated at $187,680 initially and $15,900 annually for 99.5 percent abatement. Preventive measures will cost $2,500 bringing the total cost to $190,180 initially with $15,900 annual expenditure.

An estimated grand total of $17,696,780 initially and $348,000 annually will be required to reduce AMD by approximately 90 percent for all areas of the Swatara Creek headwaters. Preventive abatement measures alone will cost a total of about 15 million dollars for the following. About 3 percent of the northwestern areas' AMD will be abated for $9,200, a 45 percent reduction of the central areas' AMD will cost 5.2 million dollars, and 93 percent abatement in the northeastern areas will cost 9.7 million dollars. Substantial recreational benefits in the Swatara Creek Watershed, 25 miles directly northeast of Harrisburg, will match the estimated cost of CMD abatement in less than five years. A benefit cost ratio of 4.06 for thirty years gives the Swatara Creek Watershed a local priority ranking of one within the Anthracite Region.

COSTS AND PRIORITIES

COSTS

The purpose and scope of this report does not permit a detailed examination or description of watershed AMD problems comparable to "Operation Scarlift" projects. Sufficient AMD water quality information was obtained for most watersheds, so the relative severity of a stream's CMD pollution could be determined and compared with other streams within a sub-basin. Numerous moderate-to-small-size watershed CMD problems were judged only from water quality data obtained during low-flow conditions. Some water quality data in this report (West Branch upstream from Chest Creek, Bennett Branch) indicates that a wide range of CMD responses exist when stream flows change. This variability was taken into account where data obtained revealed different flow and concentration responses.

Several CMD abatement methods of known cost and effectiveness were examined for their applicability to a particular watershed's pollution problems. Usually a combination of methods was recommended for any given area. Preventive methods were recommended first with follow-up treatment only being considered to the extent economically feasible. Numerous preventive and treatment methods are described in the abatement

section. Costs of these methods are indicated, along with ENR Construction Cost Indexes for a given date. Methods are also mentioned which tend to lower construction costs and insure maximum effectiveness. Methods of increasing benefits during construction of CMD projects are also given. These cost savings and additional benefits are not considered in arriving at priorities within the Basin. All costs of abatement: preventive, treatment, and annual on-going costs given in the chart below have been updated using an ENR CCI of 787 listed for June 1973. These dollar values only reflect construction cost, materials, and labor. They do not relate to any particular financing plan wherein an environmental program is established. Engineering feasibility study and design costs are not included unless specifically mentioned.

Abatement recommendations for watersheds, lacking intensified engineering feasibility studies, were made by comparing costs and abatement methods with watersheds of similar drainage area, mining, and geology. Conservative percents of effectiveness were chosen for all abatement methods. Watersheds known to have CMD conditions for which proven and economically feasible preventive methods are now lacking, did not receive recommendations for millions of dollars worth of treatment. These watersheds usually have residual levels of AMD pollution which render a stream sterile. Several tributaries to the West

Branch Susquehanna River did not receive extensive treatment recommendations for the above reasons. These considerations have resulted in lowering the sub-basin's initial and annual treatment cost. Treatment costs based solely on abating nearly all CMD would have resulted in an additional expenditure of 100 million dollars initially and 20 million dollars annually for the entire Basin. This money could be applied to watersheds such as Nescopeck Creek, for example, where annual treatment expenses could be more economically resolved by supplementing public water supplied. Other justifications for CMD treatment are realized from large watersheds that can only be restored by treatment methods.

Complete surface restoration of all strip mines in a watershed was not recommended due to diminishing pollution reduction returns. Not all strip mines within a watershed contribute CMD; in fact, some increase alkalinity and reduce acid loadings emanating from deep mines, as in the Pine Creek Watershed in Clearfield Creek.

Coal refuse banks throughout the Basin were found to be significant pollutors, especially during wet weather periods. In several watersheds, coal refuse is responsible for more pollution than mine discharges in the same watershed. Removal or restoration of coal refuse banks is usually expensive and requires special soil considerations which increases costs roughly $1,000 per acre (relative to strip mines) unless inexpensive power

plant fly ash is available.

Abandoned deep mines, the worst pollutors in nearly all watersheds throughout the Basin, have the most difficult solutions. In many watersheds of the West Branch, extensive abandoned deep mines, breached by strip mining, have few preventive solutions unless the remainder of the deep mine can be stripped out. The problems of deep mines in the Anthracite and Bituminous Fields are discussed in the CMD Summary Sections of this report. Solutions to some deep mine problems are being tested by the DER, however, more solutions are needed. In the event that new technological breakthroughs are forthcoming, new abatement costs and benefits can be developed to establish new priorities. This can be accomplished using the same system of evaluation given below.

PRIORITIES

The report this study updates lacked a quantitative dollar estimate for a wide range of benefits associated with restored lands and streams. In the absence of existing benefit data, which was being collected concurrently, the first report used a weighted point system to supplement the dollar evaluation of benefits. Benefits established in this report are related to restored utility of land and water resources. Current benefit dollar values were established for: recreation and aesthetics, hunting

(big game and small game), fresh water fishing, non-fishing stream bank recreation; increases in land values and county taxes, saw timber and pulpwood, agricultural crops, savings from reduced structural damages or costly water treatment, and general savings from reduced dredging of sediments from streams, water reservoirs, power dams, and navigational waterways. All attempts were made to avoid possible overestimations of dollar values. Attempts were first made to acquire dollar values already substantiated by surveys. Where established benefit dollar values were lacking, sound data were gathered from which dollar values were calculated. In cases where sufficient data was not available, several experts in the field were consulted. Information from these sources was cross-correlated and examined in a number of ways to determine the most realistic dollar value. In no case was the determination of a value left to pure judgement alone. It is the opinion of the authors that these dollar values will change in the future and are susceptible to economic influences which are difficult to ascertain for the entire Basin. All benefits were projected for a 30 year period. Most of the benefits would accrue for a much longer period than thirty years, and benefit cost ratios would be higher if a longer base period were used.

These dollar values for a wide range of benefits (as opposed to

points) provide an absolute scale from which priorities can be established in concert with other environmental programs. These programs will most likely require an evaluation of specific land and water uses, additional acres of affected land reclaimed by future strip mining operations, and natural resource requirements. All benefit costs reflect June 1973 ENR adjustments. Future evaluations of benefits and costs can use June 1973 ENR indexes as a reference or base value. Over the last four years (from 1969 to 1973) construction costs, material costs, and common labor index values indicate equivalent gains. Labor costs follow construction cost changes more closely. Construction costs have a more unique, distinct, and somewhat predictable pattern of change. During the late Fall and Winter months rates of increase are less. In April, construction cost rates increase, and are always greater than before or following that period.

In establishing benefits on a local and comprehensive basis, several basic considerations were given:

1. Upstream reductions in acid loadings, to varying degrees, always result in downstream increases of alkalinity.

2. Tributaries discharging large acid loadings could not be excluded from a sub-basin's comprehensive program and damages caused by these watersheds were proportioned to include damages they cause to receiving streams.

3. Main stream tributaries with small acid loading and some natural alkalinity accrue local benefits but contribute less to a comprehensive abatement program.

4. Main stream tributaries with severe and wide spread AMD pollution, and little natural alkalinity are unlikely to accrue local benefits but will accrue large downstream benefits. These watersheds have high comprehensive priorities relative to their local priority rankings.

Depending on the abatement program chosen for a given watershed, total costs accumulate in varying ways. Areas which accrue arge stream oriented benefits usually justify some treatment expenditures. batement programs with low treatment costs generally have the best enefit cost ratios. Stream oriented benefits (fishing, non-fishing tream bank aesthetics, and structural damages) vary greatly and epend upon the severity of a stream's pollution and its potential for upporting a sport fishery. Land oriented benefits for one acre of eclaimed strip mine total about $59 per year. Present costs of land estoration in the Bituminous Region can be equaled by <u>land</u> improvement enefits in 34 years without regard to water quality improvements. Addition of tream oriented benefits will greatly decrease the time span over which enefits must be computed. Current costs for complete surface restortion in the Anthracite Region, where abatement is more costly, can be natched by <u>land</u> oriented benefits within 81 years. Substantial stream

benefits also decrease this time.

Priority rankings were established by evaluating benefit-cost ratios for the first 30 years. Priority evaluations using the accumulative time period avoid low priority rankings of watersheds which only have low first-year benefit/cost ratios.

The following chart lists all watersheds and their abatement costs, and associated benefits. Priority rankings were established from 30 year period benefit/cost ratios and are listed on Table 1. The Chest Creek to Clearfield Creek reach is ranked highest, on a comprehensive basis, primarily due to small amounts of CMD which can be abated at low first cost. The Tioga and Swatara Creek Watersheds are ranked high due to benefits realized from large multi-purpose dams. The Tioga Watershed is ranked high due to flood control and increased recreational potential. The Swatara Watershed is ranked high due to increased recreational potential and public water supply. From Bald Eagle Creek to the mouth of the West Branch relatively small expenditures will restore streams which are moderate to weakly acid. In this reach preventive abatement measures alone should abate much of the CMD. Abatement of CMD in local priority watershed 6 through 10 will eliminate most of the CMD entering the West Branch. Within the Anthracite Region Catawissa Creek was ranked just below Swatara Creek. The successful sealing of water level tunnels in the Catawissa Watershed should eliminate most of the pollution from this watershed. Remaining

priorities in the Anthracite Region are low, on a comprehensive basis, due to extensive treatment cost and difficulties in abating large amounts of CMD discharging from extensive mine pool complexes. Should less costly projects be successful in reducing pollution from anthracite mines, along with increases in benefits , these areas would receive higher priority rankings. Hydrological studies and new technology should aid these areas which have exceedingly large discharges of CMD. Priority rankings established during this study were based upon the accumulation of present benefits. As additional benefits accumulate, new benefit-cost ratios can be calculated to establish new priority rankings.

BENEFITS AND COSTS ASSOCIATED

Region	Sub-basin	WATERSHEDS	RECL-AIMED ACREAGE	ABATEMENT COSTS: Initial Preventive (million $)	ABATEMENT COSTS: Initial Treatment (million $)	ABATEMENT COSTS: Annual Treatment (thousand $)	DOLLAR VALUE OF STR: Fishing	DOLLAR VALUE OF STR: Non-Fishing	DOLLAR VALUE OF STR: Struct
BITUMINOUS COAL REGION	TRIBUTARIES OF THE WEST BRANCH SUSQUEHANNA SUB-BASIN	UPSTREAM FROM CHEST CREEK	4,000	12.0	0	0	16,950	325,600	[illegible]
		CHEST CREEK	1,388	2.5	0	0	8,800	30,800	[illegible]
		CHEST CREEK TO CLEARFIELD CREEK	1,388	2.5	0	0	124,650	88,000	[illegible]
		ANDERSON CREEK	1,900	3.8	0.3	58	24,250	88,000	[illegible]
		CLEARFIELD CREEK	7,220	13.0	4.4	400	270,400	651,200	3
		CLEARFIELD CREEK TO MOSHANNON CREEK	9,000	18.0	0	0	38,000	140,800	3
		MOSHANNON CREEK	6,000	12.0	0	0	18,700	176,000	5
		MOSHANNON CREEK TO SINNEMAHONING CREEK	2,100	5.0	0	0	87,800	110,000	[illegible]
		SINNEMAHONING CREEK	4,500	9.0	1.5	400	259,600	492,800	1
		SINNEMAHONING CREEK TO BALD EAGLE CREEK	4,500	9.0	1.5	400	220,200	132,000	1,
		BALD EAGLE CREEK	8,000	16.0	7.7	900	54,725	242,000	
		BALD EAGLE CREEK TO MOUTH OF WEST BRANCH	1,944	4.1	0.7	200	507,100	176,000	
		TOTAL (WEST BRANCH)	51,940	106.9	16.1	2,358	1,631,175	2,653,200	18,
	SINGLE SUB-BASINS	JUNIATA RIVER	850	1.5	1.6	320	2,050	268,400	
		TIOGA RIVER	1,000	2	2.2	440	50,350	180,400	1,
ANTHRACITE COAL REGION	TRIBUTARIES OF THE NORTH AND MAIN BRANCH SUB-BASIN	LACKAWANNA RIVER	800	4.0	2.9	600	17,850	180,400	5,
		WYOMING VALLEY LACKAWANNA TO NESCOPECK	1,200	6.0	4.4	1,000	41,550	220,000	6,
		NESCOPECK CREEK	1,400	7.0	2.2	400	96,250	145,200	[illegible]
		CATAWISSA CREEK	500	5.0	0	0	107,100	206,800	[illegible]
		SHAMOKIN CREEK	1,200	6.2	2.2	400	86,650	202,400	1,
		MAHANOY CREEK	1,600	11.0	2.9	400	143,400	286,000	1,0
		RAUSCH CREEK	310	1.4	2.2	300	42,750	132,000	7
		WICONISCO CREEK	659	3.41	0.47	50	2,650	74,800	6
		SWATARA CREEK	2,468	15.18	2.52	348	58,550	250,800	8
		TOTAL ANTHRACITE REGION	10,137	59.2	19.8	3,498	596,750	1,698,400	17,0
		GRAND TOTAL	63,927	169.6	39.7	6,616	2,280,325	4,800,400	36,8

WITH LAND AND STREAM RESTORATION

...NTED BENEFITS		DOLLAR VALUE OF LAND ORIENTED BENEFITS						SUMMARY OF BENEFITS			
...ments	Total	Land & Tax	Agriculture	Timber	Hunting	Recreation & Aesthetics	Total	Total Benefits (million $)		Benefit/Cost Ratio	
								1yr.	30yrs.	1yr.	30yrs.
3,400	346,950	36,000	20,000	20,000	37,280	120,000	233,280	0.58	17.4	0.05	1.45
1,180	41,080	12,492	69,400	69,400	12,936	41,640	205,868	0.25	7.41	0.10	2.96
1,180	214,330	12,492	69,400	69,400	12,936	41,640	205,868	0.42	12.60	0.17	5.04
1,615	114,065	17,100	9,500	9,500	17,708	57,000	110,808	0.22	6.75	0.05	1.16
6,137	930,737	64,980	36,100	36,100	67,290	216,600	421,070	1.35	40.55	0.08	1.38
7,650	189,850	81,000	45,000	45,000	83,880	270,000	524,880	0.72	21.45	0.04	1.20
5,100	204,800	54,000	30,000	30,000	55,920	180,000	349,920	0.55	16.65	0.05	1.38
1,785	200,185	18,900	10,500	10,500	19,572	63,000	122,472	0.32	9.70	0.06	1.94
3,825	757,825	40,500	22,500	22,500	41,940	135,000	262,440	1.02	30.60	0.09	1.36
3,825	357,225	40,500	22,500	22,500	41,940	135,000	262,440	0.62	18.60	0.06	0.83
6,800	304,325	72,000	40,000	40,000	74,560	240,000	466,560	0.77	23.13	0.03	0.46
1,677	685,177	17,766	98,700	98,700	18,398	59,220	292,784	0.98	29.34	0.20	2.72
44,174	4,346,549	467,730	473,600	473,600	484,360	1,559,100	3,458,390	7.78	233.6	0.08	1.82
721	271,971	7,650	1,690	4,250	7,921	25,500	47,011	0.32	9.60	0.09	0.76
850	232,600	9,000	5,000	5,000	9,320	2,400,000	2,428,320	2.66	79.83	0.57	4.58
680	203,930	7,200	1,600	4,000	7,456	24,000	44,256	0.25	7.50	0.03	0.30
1,020	268,570	10,800	2,400	6,000	11,184	36,000	66,384	0.33	10.05	0.03	0.25
1,190	242,540	12,600	2,800	7,000	13,048	42,000	77,448	0.32	9.63	0.03	0.45
425	315,125	4,500	1,000	2,500	4,660	15,000	27,660	0.34	10.30	0.07	2.06
1,020	291,270	18,000	2,400	6,000	11,184	36,000	73,584	0.36	10.95	0.04	0.54
1,360	431,760	14,400	3,200	8,000	14,912	48,000	88,512	0.52	15.61	0.04	0.60
263	175,713	2,790	620	1,550	2,890	9,300	17,150	0.19	5.80	0.05	0.46
560	78,610	5,931	1,320	3,295	6,141	19,770	36,457	0.12	3.45	0.03	0.64
2,097	312,247	22,212	4,900	12,340	23,001	3,750,000	3,812,453	4.12	123.6	0.21	4.06
8,615	2,320,765	93,433	20,240	50,685	94,476	3,980,070	4,243,904	6.55	197.0	0.08	1.07
54,360	7,171,885	582,813	500,530	533,535	596,077	7,964,670	10,177,625	17.31	520.0	0.09	1.27

BIBLIOGRAPHY

1. Anthracite Research and Development Co., Inc., Consulting Engineers, Rausch Creek Watershed, Mine Drainage Pollution Abatement Project, Department of Environmental Resources, Commonwealth of Pennsylvania.

2. Anthracite Research and Development Co., Inc., Consulting Engineers, Swatara Creek, Mine Drainage Pollution Abatement Project, Part III, Department of Environmental Resources, Commonwealth of Pennsylvania.

3. Baker, Michael, Jr., Inc., Analysis of Pollution Control Costs, Appalachian Regional Commission, 1666 Connecticut Avenue, N.W., Washington, D. C., 20235, February, 1973.

4. Baltimore District, Corps of Engineers, Occurrence and Effects of Mine Drainage in the Tioga River Basin, Susquehanna River Basin, Mine Drainage Study, February, 1972.

5. Battlelle Memorial Institute, Columbus Laboratories, The Impact of Mine Drainage Pollution on Industrial Water Users in Appalachia, Appendix A to Acid Mine Drainage in Appalachia, A report by the Appalachian Regional Commission, March 1969.

6. Becher, A. E., Ground Water in Pennsylvania, Department of Environmental Resources, Commonwealth of Pennsylvania, Bureau of Topographic and Geologic Survey, Educational Series No. 3, March, 1973.

7. Berger Associates, Inc., Consulting Engineers, Swatara Creek, Mine Drainage Pollution Abatement Project, Part II, Department of Environmental Resources, Commonwealth of Pennsylvania, 1972.

8. Biggs, R. B., Chesapeake Biological Laboratory, University of Maryland, Sources and Distribution of Suspended Sediment in Northern Chesapeake Bay, Marine Geology, Elsevier Publishing Company, Amsterdam, The Netherlands, 9 (1970), pp. 187-201.

9. Conable - Sampson - Van Kuren - Huffcut - Gertis, Engineers and Surveyors, Dents Run, Mine Drainage Pollution Abatement Project, Department of Environmental Resources, Commonwealth of Pennsylvania, 1972.

10. Department of Environmental Resources, Annual Report 1970, Commonwealth of Pennsylvania, Anthracite Division, pp. 41-43, 50-54.

11. Department of Environmental Resources, Annual Report 1970, Commonwealth of Pennsylvania, Bituminous Division, pp. 121-125, 135, 139, 140-145.

12. Department of Environmental Resources, Annual Report 1971, Commonwealth of Pennsylvania, Anthracite Division, pp. 109.

13. Department of Environmental Resources, Annual Report 1971, Commonwealth of Pennsylvania, Bituminous Division, pp. 103-106, 115.

14. Edmunds, William E., Coal Reserves of Pennsylvania: Total, Recoverable, and Strippable (January 1, 1970), Department of Environmental Resources, Commonwealth of Pennsylvania, Bureau of Topographic and Geologic Survey, Information Circular 72, 1972.

15. Edmunds, William E., Koppe, Edwin F., Coal in Pennsylvania, Department of Environmental Resources, Commonwealth of Pennsylvania, Bureau of Topographic and Geologic Survey, Educational Series No. 7, March, 1973.

16. English Engineering Corporation, English Run Watershed, Mine Drainage Abatement Project, Department of Environmental Resources, Commonwealth of Pennsylvania, 1971.

17. Gannett Fleming Corddry and Carpenter, Inc., Acid Mine Drainage Abatement Measures for Selected Areas Within the Susquehanna River Basin, Federal Water Pollution Control Administration, Engineering Report, Contract WA 66-21, 1968.

18. Gannett Fleming Corddry and Carpenter, Inc., Engineers, Mine Drainage Pollution Abatement Measures for the Beech Creek Watershed, Department of Mines and Mineral Industries, Commonwealth of Pennsylvania, 1970.

19. Gannett Fleming Corddry and Carpenter, Inc., Engineers, Swatara Creek, Mine Drainage Abatement Project, Part I, Department of Environmental Resources, Commonwealth of Pennsylvania, 1972.

20. Hartman, Fred E., In Pennsylvania, Hunting is Big Business, Pennsylvania Game News, Volume 44, No. 9, pp. 26-33. September, 1973.

21. Hollowell, Jerrald R., Hydrology of the Abandoned Coal Mines in the Wyoming Valley, Pennsylvania, Unpublished Report, United States Geological Survey, Water Resources Division, in cooperation with the Pennsylvania Department of Environmental Resources and the United States Bureau of Mines.

22. Hollowell, Jerrald R., Hydrology of the Pleistocene Sediments in the Wyoming Valley, Luzerne County, Pennsylvania, Department of Environmental Resources, Bureau of Topographic and Geologic Survey, Water Resources Report 28, 1971.

23. Hollowell, Jerrald R., Koester, Harry E., Ground Water Resources of Lackawanna County, Pennsylvania, U. S. Geological Survey, in cooperation with the Bureau of Topographic and Geologic Survey, Pennsylvania Department of Environmental Resources.

24. Kohler, Walter V., Pennsylvania Reclamation and Mine Drainage Control Programs, Paper presented at Short Course on Controlling Water Pollution in Coal Mining, October 4-6, 1972, Pennsylvania State University.

25. Lovell, H. L., Chemistry of Mine Drainage Formation, Paper presented at Short Course on Controlling Water Pollution in Coal Mining, October 4-6, 1972, Pennsylvania State University.

26. Peters, Albert E., Associates, Engineers - Designers - Consultants, Lackawanna River Watershed, Mine Drainage Pollution Abatement Project, Part I, Department of Environmental Resources, Commonwealth of Pennsylvania, August, 1971.

27. Rhodes, Ralph L., Davis, Robert S., Mine Drainage in the Susquehanna River Basin, Federal Water Pollution Control Administration, Charlottesville, Virginia, 22901, 1968.

28. Rivkin/Carson and Arthur Edwards Associates, Development of a Priority Determination Procedure, Appalachian Regional Commission, 1666 Connecticut Avenue, N.W., Washington, D. C., 20235.

29. Sanders and Thomas, Inc., Consulting Engineers, Wiconisco Creek Watershed, Mine Drainage Pollution Abatement Project, Department of Environmental Resources, Commonwealth of Pennsylvania, 1973.

30. Skelly and Loy, Engineers and Consultants, Alder Run Watershed, Acid Mine Drainage Pollution Abatement Project, Department of Environmental Resources, Commonwealth of Pennsylvania, July, 1970.

31. Skelly and Loy, Engineers and Consultants, Clearfield Creek and Moshannon Creek, Mine Drainage Pollution Abatement Project, Department of Environmental Resources, Commonwealth of Pennsylvania, 1973.

32. Skelly and Loy, Engineers and Consultants, Penn Environmental Consultants, Inc., Processes and Procedures to Control Pollution from Mining Activities, U. S. Environmental Protection Agency, Contract 68-01-1830, August 1973.

33. Skelly and Loy, Engineers and Consultants, Muddy Run Watershed, Mine Drainage Pollution Abatement Project, Department of Environmental Resources, Commonwealth of Pennsylvania, December, 1971.

34. Stuart, Wilbur T., Schneider, William J., Crooks, James W., Swatara Creek Basin of Southeastern Pennsylvania, An Evaluation of Its Hydrologic System, U. S. Department of Interior, U. S. Geologic Survey Water - Supply Paper 1829, 1967.

35. Susquehanna River Basin Study Coordinating Committee, Susquehanna River Basin Study, Appendix F - Water Supply and Water Quality, June, 1970.

36. U. S. Department of Agriculture, Climatic Summary of the United States, Weather Bureau, Climatic Data from 1931 to 1952, Section 88 - Central Pennsylvania.

37. U. S. Department of Commerce, Climatic Summary of the United States - Supplement for 1951 through 1960, Pennsylvania, Weather Bureau, Climatography of the United States No. 86-32.

38. United States Department of the Interior, Geological Survey, Water and Industry, United States Government Printing Office, stock number 2401-2095, 1972.

39. U. S. Department of Interior, National Survey of Fishing and Hunting, 1970, Bureau of Sports Fisheries and Wildlife, Resource Bulletin 95.

39.1. U. S. Geological Survey, Erosion and Sediment, Water in the Urban Environment Series, 1972.

40. U. S. Geological Survey, Monthly Water Resources Summary for Pennsylvania, Water Resources Division, P. O. Box 1107, Harrisburg, Pennsylvania, 1972 and 1973.

41. Warg, Jamison B., Traverse, Alfred, A Palynological Study of Shales and Coals of Devonian - Mississippian Transition Zone, Central Pennsylvania, Geoscience and Man VII, AASP 1971 Proceedings.

42. Williams, Kenneth F., Reed, Lloyd A., Appraisal of Stream Sedimentation in the Susquehanna River Basin, U. S. Department of Interior, U. S. Geologic Survey Water-Supply Paper 1532-F, 1972.

43. Barr, David; Chief Assessor-Centre County; Phone Interview; Land Values and Taxes, Historical Data.

44. Baskin, Leon; Department of Environmental Resources, Harrisburg; Personal Interview; SL-Project Information on AMD Studies, Q.S., Miscellaneous Water Quality, and Studies in Progress or Reports in Press.

45. Beacher, Arthur; Department of Environmental Resources, Pottsville Field Office; Personal Interview; Information on Anthracite Coal Field Q.S. Projects, Water Quality, Mine Outfalls, Coal Mining Activities, Bids on Q.S. Projects, Cost of Reclamation Work.

46. Bradford, Arthur; Chief of Fisheries Division-Pennsylvania Fish Commission; Personal Interview; Benefit Information Regarding Fishing, Hunting and Recreational Plans for Pennsylvania.

47. Cassick, John; Dairy Farmer (Bituminous Coal Region); Personal Interview; Milk Production and AMD.

48. Ciolkosz, Dr. Edward; Pennsylvania State University; Personal Interview; Percent of Strip Lands with Potential for Agriculture Use.

49. Conklin, Edward L.; Office Manager-James Williams Real Estate Dealer for Centre and Clearfield Counties; Phone Interview; Current Market Values and Demands for Mountain Lands.

50. Dalberto, Alfred; Department of Environmental Resources, Harrisburg; Personal Interview; SL-Project Information on AMD Studies, Q.S., Miscellaneous Water Quality, and Studies in Progress or Reports in Press.

51. DePolio, Walter; Department of Environmental Resources, Wilkes-Barre Field Office; Personal Interview; Information on Q.S. Projects, Mining Activities, Deep Mine Pumping and Proposed Projects in the Northern Field.

52. Ferko, M.; Department of Environmental Resources, Ebensburg Field Office; Phone Interview; Discussions on Q.S. Projects Past, Present and Future.

53. Fitzgerald, Daniel; Environmental Protection Agency, Region III, Philadelphia; Personal Interview; Water Quality from Storet System.

54. Fowler, Don; Department of Environmental Resources, Harrisburg; Personal Interview; Discussions on Sealing Water Level Tunnels in Catawissa Creek Watershed.

55. Gustafson, Carl; Department of Environmental Resources, Pottsville Field Office; Personal Interview; Information on Anthracite Coal Field, Q.S. Projects, Water Quality, Mine Outfalls, Coal Mining Activities, Bids on Q.S. Projects, Cost of Reclamation Work.

56. Hamlen, Dale; Department of Environmental Resources, Harrisburg; Personal Interview; Discussions on Sealing Water Level Tunnels in Catawissa Creek Watershed.

57. Harper, Harrison; Department of Environmental Resources, Pottsville Field Office; Personal Interview; Information on Anthracite Coal Field Q.S. Projects, Water Quality, Mine Outfalls, Coal Mining Activities, Bids on Q.S. Projects, Cost of Reclamation Work.

58. Hawn, Larmer F.; Pennsylvania Department of Forestry-Timber Sales; Phone Interview; Value of Timber Cuttings Per Acre on Unreclaimed lands.

59. Hebel, Joseph; Bell Telephone Company-Facility Engineer; Phone Interview; How AMD Affects Underground Transmission Lines.

60. Hinish, Dr. W. Wayne; Pennsylvania State University-College of Agriculture; Personal Interview; Past and Present Dollar Value of Farm Produce, Crops, Dairy and Beef.

61. Hohman, John; Retired President of Hazelton First National Bank; Personal Interview; General Economy of the Anthracite Region.

62. Ickes, Thomas C.; Pennsylvania Department of Transportation, Phone Interview; Additional Cost for Bridge and Highway Construction Due to AMD.

63. Joyce, Arthur; Department of Environmental Resources-Deep Mine Inspector for the Northern Anthracite Field; Personal Interview; Discussed Water Level Tunnel Sealing, Mining Activities in the Northern Field, and Mine Outfall Activity.

64. Koval, Paul; Department of Environmental Resources, Kingston Field Office; Personal Interview; Water Quality for Anthracite Region.

65. Lovell, Dr. Harold; Pennsylvania State University; Personal Interview; Discussion of AMD Formation in the Bituminous Fields.

66. Lucas, H. W.; Lucas Farm Equipment; Personal Interview; Crop Values and Tillable Acreage Values.

67. Miller, Clarence; Department of Environmental Resources; Deep Mine Inspector for Wiconisco Creek Area; Personal Interview; Water Level Tunnel Sealing, Mining Activities in the Wiconisco Creek Area and Mine Outfall Activity.

68. Molinski, A. E.; Department of Environmental Resources, Ebensburg Field Office; Phone Interview; Discussions on Q.S. Projects Past, Present and Future.

69. Mutchler, Norman E.; Berger Associates, Harrisburg; Personal Interview; Water Quality, Bennett Branch, Sinnemahoning Creek.

70. Pawlush, Lawrence; Department of Environmental Resources, Kingston Field Office; Personal Interview; Water Quality for Anthracite Region.

71. Prall, Edward; Berger Associates, Harrisburg; Personal Interview; Water Quality, Bennett Branch, Sinnemahoning Creek.

72. Rhodes, Ralph L.; Environmental Protection Agency, Region III, Philadelphia; Personal Interview; Water Quality from Storet System.

73. Rodgers, Leonard; Department of Environmental Resources-Deep Mine Inspector for Catawissa-Nescopeck Creek Area; Phone Interview; Discussed Water Level Tunnel Sealing, Mining Activities in the Catawissa-Nescopeck Creek Area and Mine Outfall Activity

74. Root, Gerald; United States Soil Conservation, Harrisburg; Phone Interview; Cost of Sediment Removal and Tons of Sediment Being Transported from Strip Mines in the Basin.

75. Schneider, Robert; Albert Peters Associates; Phone Interview; Water Quality Lower Lackawanna Valley.

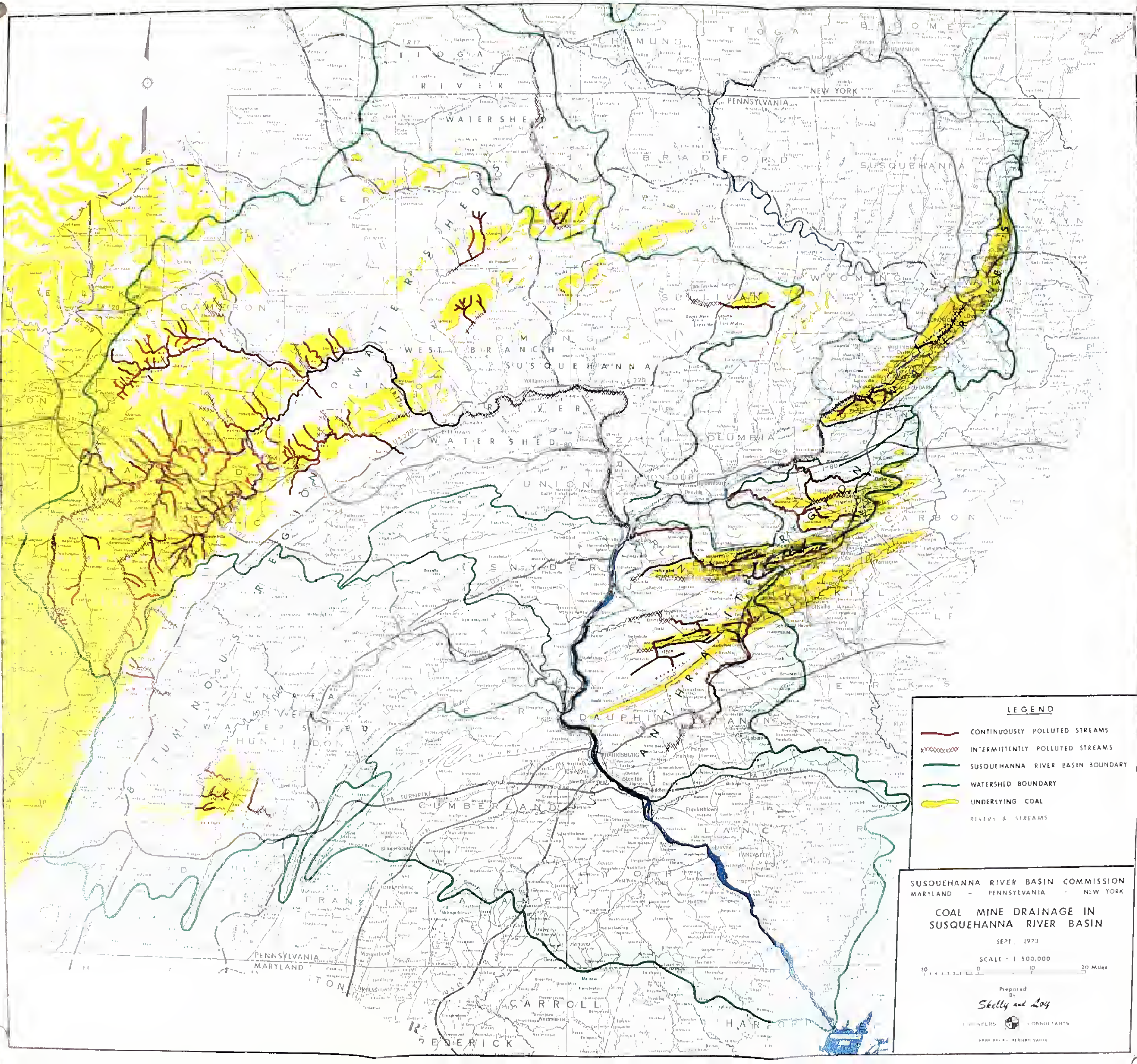
76. Small, W.; Pennsylvania Power and Light Company; Phone Interview; Organic Sediments in the Lower Susquehanna River Basin.

77. Williams, E. G.; Pennsylvania State University, Department of Geology and Geophysics; Personal Interview; Geology of Pennsylvania.

78. Wilson, Charles; United States Soil Conservation, Harrisburg; Phone Interview; Cost of Sediment Removal and Tons of Sediment Being Transported from Strip Mines in the Basin.

79. Yaccino, M.; Department of Environmental Resources, Pottsville Field Office; Personal Interview; Information on Anthracite Coal Field Q.S. Projects, Water Quality, Mine Outfalls, Coal Mining Activities, Bids on Q.S. Projects, Cost of Reclamation Work.

80. Yachin, Gideon; Geo-Technical Services, Harrisburg; Phone Interview; Recent Water Quality, Wyoming Valley Area.


LEGEND
CONTINUOUSLY POLLUTED STREAMS
INTERMITTENTLY POLLUTED STREAMS
SUSQUEHANNA RIVER BASIN BOUNDARY
WATERSHED BOUNDARY
UNDERLYING COAL
RIVERS & STREAMS
SUSQUEHANNA RIVER BASIN COMMISSION
MARYLAND - PENNSYLVANIA - NEW YORK
COAL MINE DRAINAGE IN SUSQUEHANNA RIVER BASIN
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SUSQUEHANNA
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